PERMANENT WAY
ROLLING STOCK
AND
TECHNICAL WORKING
OF
RAILWAYS.
WITH AN APPENDIX ON
WORKS

BY

CH. COUCHE

Inspecteur Général des Mines, Professeur de Construction et de Chemins de fer à l'École des Mines, Président de la Commission permanente des Règlements et des Inventions concernant les chemins de fer, Président du Comité consultatif des machines à l'Exposition universelle de 1878, et de la classe 64 (Matériel des chemins de fer) du jury international, etc.

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J. EDWARDS WILSON

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PERMANENT WAY
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TECHNICAL WORKING
OF
RAILWAYS

BOOK SECOND.
CARRYING-STOCK.

CHAPTER I.

GENERAL FEATURES OF ORDINARY RAILWAY ROLLING-STOCK.

1. The vehicles which run on our iron-roads are of simple construction, simpler indeed, generally, than that of the highly finished carriages to be found on common roads. Considered apart, and independently of their mutual relations, they do not differ, essentially, from ordinary carriages. But for the projecting flanges of their wheels (2), and the more or less complete parallelism of their axles (5), which prevents their *turning sharp*, they could run on common roads. They have not at the same time, the elegance of shape and harmony of proportions which can be given to ordinary carriages. They can be painted and gilded, and richly got up; but it is difficult to make them handsome.

The peculiarities which they present, arise partly from the twofold condition of running upon edge-rails, and travelling always coupled together, more or less in number. The second condition is only, moreover, the consequence of the first.

At any rate, if rolling-stock is made for the permanent way, it is equally

true to say that the railway, at least as regards its ground plan, is made for the rolling-stock. Thus the very onerous condition, of curves of large radius, much less strict now-a-days, is for the most part, the consequence of the parallelism of the axles. As to the limit to the steepness of gradients, far less absolute, by the way, than formerly, that concerns the mode of traction, and not the carrying-stock: for the present, therefore it need not be gone into.

Railway rolling-stock differs from that in use on common roads, in the following points :

1. Additions of flanges to the tyres of the wheels;
2. Wheels being fixed on the axles;
3. Conicity of the tyres;
4. Parallelism of the axles;
5. Position of the wheels under the bodies, which project laterally;
6. Application of the load on bearings outside the wheels.

Let us examine rapidly, these different points.

2. *Flanges*. — Properly speaking, these are safety-appliances; the part they play is not constant. In a perfect state of things they would not act, unless on a curve, and only then below a certain limit of radius. In reality, they are, however, absolutely indispensable; and it is unquestionably a most unlooked for result due to the happy carrying out of numerous conditions, that their slight projection, comprised between $^3/_4$ " and 1 $^1/_2$ ", should suffice to keep the wheels on the rails. Sundry contrivances tend, besides, to reduce as much as possible, their intervention, and the resistances they induce.

3. *Fixity of the wheels on the axles*. — The normal state of railways is a straight line. If this is departed from, it is on account of considerations of economy imposed by the nature of the ground, and on account of the necessity of increasing the distance between two points situated at different levels, so as to spread the difference over a sufficient length. The rolling-stock by far the most in use, that which is called English or rigid stock, is arranged specially for straight lines. It is convenient to study this material first. We shall examine afterwards: 1. the modifications by which, without losing its essential character, it can be made suitable for running on curves; indispensable in all cases, were it only for crossings:

2. the special arrangements which are had recourse to when these modifications are, or seem to be insufficient.

The flanges are, as we have already said, safety-appliances. But for security, for economy of traction and maintenance, they ought to come into play as seldom as possible.

The vehicles ought to tend to keep themselves to the axis of the line of rails, by the sole fact of their construction, and independently of the action of the flanges, which have, as we have seen (I, 199), a certain amount of play between the rails.

Several accidental causes tend either to make the pair of wheels slip crossways to the line, or to give the axle a position oblique thereto, and consequently to press one of the flanges against the corresponding rail.

It is against this obliquity, arising whether from the load on the two wheels being unequal, from an inequality of lubrication and consequently in the resistance of the two bearings, or from the traction acting obliquely or excentrically, that the solid connection between the two wheels by means of the axle is directed. Thus one wheel cannot obey the causes which induce it to go on before the other, unless one of them slips on its rail: so that friction comes in as a regulator, as a preserver of the normal position of the axle.

Arrangements which experience or habit has consecrated, are every now and then put in question. The solid connection of the wheels and the axles has not escaped that praiseworthy spirit of criticism, which deals not with words, but with proofs: and it has been asked, if that solid connection is really necessary. In England, distinguished engineers, while admitting its utility with imperfect rolling-stock and permanent way, are convinced that the normal situation is the freedom of the wheels from each other, and that such shall one day prevail; as the remedy must disappear while imperfections continue to be reduced. Experience, and the most suitable of all to settle or enlighten the question, that of articulated rolling stock (182) has not confirmed that view; if the solid connection between the wheels is to disappear, it will doubtless be not soon, the state of perfection to which it is suitable, being neither attained, nor nearly so. The independence of the wheels, without doubt, presents a notable economical advantage, in a slower wear of the tyres; but at high speeds, it reacts in a manner evidently unfavourable on the motion of the vehicles. This is a capital consideration; and ought to go before that of economy; besides we are not at all certain that, at the end of the account, and taking in lubrication and maintenance of wheels and axles, the economy would be on the side of the loose wheels. In the actual state of things, there are no grounds for the

adoption of the loose wheels, excepting under the conditions of unusually sharp curves, and short wheel base, conditions, of which the provisional line over mont Cenis offered an example, to which we shall return later on.

4. *Conicity of tyres.* — It is often supposed that the conicity of the tyres was introduced, solely on account of the curves so as to compensate for, or reduce the difference of the running of the two conjugate wheels. This is, in effect, one of the services rendered by the conicity; but beyond those exceptional cases where it is pushed very far, on account of the sharpness of the curves, it is fixed entirely with reference to running on straight lines. Its utility from this point of view has already, however, been pointed out (I, 55) as well as on entering a curve, taking one pair of wheels into consideration (I, 199). It has been shown that thanks to the conicity, out of the very drawback itself within certain limits, comes the remedy for the obliquity or transversal displacement of the axle. In the case of obliquity of the axle, the backward wheel runs on a larger radius, and the forward wheel on a smaller radius than the mean radius of the wheel, and the axle is thus brought back to the normal position; but it is only brought back thereto, even if the displacing cause has ceased, after a series of oscillations (I, 55).

In the case of lateral displacement, normal to the line, produced, for example, by a violent side-wind, on a curve through the outer rail being too high for the velocity (I, 200), the play of the conicity draws off the flange from the rail it was pressing against, and brings together the flange and the rail on the other side; but here again, substituting for a permanent contact, on account of the difference of the two radii on which the two wheels are running, a state of oscillation, aggravated as far the body is concerned, by the elasticity of the suspension springs, and admissible only so ar as the conicity from which it arises, is of small extent.

It might be thought, at first sight, that the conicity, substituting obliquity or a state of oscillation, for the normal position of the axle only draws away the flange from the head of the rail in front of the point where the wheel rests on the rails by bringing it as much closer behind that point; so that, in that respect, there would be nothing gained. At the first moment, the point of contact of the flange and the rail, at first to the right of the point of support of the tyre, becomes removed at in effect to behind that point. But the other wheel, getting forward, brings back the axle to the normal position, from which it goes back, to return and pass beyond again, and the

movement continues thus, substituting oscillation instead of permanent contact between the flange and the rail, and that with advantage to the traction, and without affecting in any objectionable manner, the movement of the vehicle even at the highest speeds, provided, as has been said, that the conicity does not much exceed $\frac{1}{20}$.

5. *Parallelism of the axles.* — From the point of view which we are now taking, that of the conditions most favourable for running along a straight line, the parallelism of the axles is self-evident.

They should be normal to the line; and should therefore be parallel, if the line is straight. This is only one case in particular of the theoretical condition, to which we shall recur, of their convergence towards the centre of the curves of the line.

6. *Position of the wheels under the body.* — We have already remarked (I, 5) that on railways the wideness of the bodies is independent of the gauge of the line, that is to say, of the distance between the two wheels fixed on the same axle; it is thanks to this independence, arising from the position of the wheels under the bodies, that the ordinary gauge of 4 ft. 8 ½ ins. suffices for the different requirements of the traffic. This is not the case with vehicles on common roads (with the exception of certain trucks with very small wheels), whose conditions of stability are quite different. Running on unequal surfaces with a curved cross section, often loaded on the top, these vehicles would be completely without stability if the load projected over its base of support on the ground and if, at the same time, the position of the body above the wheels, which are (the hind ones at any rate) of great size, should exaggerate the height of the centre of gravity. Upon rails, vehicles run no risk of upsetting, and the less so, as the load is not accumulated on the roof, as it is on stage-coaches. The load can then be much broader than its base of support; but the underneath position of the wheels necessarily limits their diameter, which is a disadvantage for haulage, partly compensated for by the less weight of the wheels. On the other hand, the pressure of the rails upon the flanges put a strain on the axle proportional to the diameter of the wheels. This diameter rarely exceeds 3 ft. 4 ins. measured to the middle of the tyre; and when a considerably greater diameter has been adopted, as on the "Great Western", for example, it was necessary, to avoid raising the floor, to let the wheels up into the bodies, covering them with boxes (*c. c.* Pl. V, *figs.* 12 and 13, and T T, Pl. II, *figs.* 9 to 13), an arrangement which puts the distribution of

the bodies and the distance between the wheels into a troublesome mutual dependence.

It is besides from reasons of convenience and not from the point of view of stability, that the load is not concentrated towards the upper part of the bodies.

7. *Gauges for works: for rolling-stock; for loading.*—The transversal dimensions of the bodies or loads are limited not by the gauge of the line itself, but by the profile of the over-bridges, and so on. These dimensions ought to be laid down on a diagram showing the *extreme outline of the rolling-stock*, which itself should be laid down on a diagram showing the extreme inside dimensions of the various works along the line through which the rolling-stock has to pass. But in this latter a considerable play ought to be allowed, to make up for the oscillations due to the springs, and even, if possible, for the accidental opening of a door; and on the other hand, from the road being in any way raised, the settlement of a tunnel, and so on For open goods-waggons (trucks and platforms) great care has to be taken that no part of the load project beyond the regulation outline, Hence, the *loading gauge*, a polygonal bar suspended from posts, and shewing all the portion of the *rolling-stock gauge* lying above the level of the bodies, and under which the waggons ought to pass freely. It is sometimes prudent to provide against a slight disturbance of the gauge caused by any little disarrangement of the load, and not to load fully up to the gauge.

Fig. 17, Pl. X, represents several examples of works and loading gauges. ("Paris-Méditerranée", "Eastern of France", "Midi", "Paris-Ceinture".)

The stock which has to run over several lines, ought of course to be loaded by the minimum gauge.

In France the loading gauge on the "Ceinture" line rules the most of the other lines, without prejudice to the conditions of their own particular outlines; those whose overworks dimensions allow a gauge passing beyond the ruling gauge can apply it to the stock which does not leave their own system, and some of them take advantage of this.

In Germany the numerous trunk lines constructed without previous concert, present disparities, the disadvantages of which became felt, as the lines became joined together. Matters have however been therein greatly improved, thanks to the excellent practice, adopted by the managements of the lines and engineers, whether Government or attached to the Companies, to meet together periodically to discuss and regulate, in

common accord, all points of general interest. As far back as 1857, the meeting at Vienna proposed a normal overworks outline (*Normal Profil des lichten Raumes*) (*fig.* 17) leaving sufficient clearance for the rolling-stock, and to be in force over the whole of the lines of the German union. The meeting at *Trieste* in 1858 adopted this outline, a *desideratum* which has never been modified since. The Companies made a general inspection of their old lines, to determine all the points where the *normal outline* was infringed on; and they put all these right with the *normal outline*, in every case where such was possible without too great expense. But each management has its own particular gauge (*Durchfahrts Profil*) inforced by its old lines, and a corresponding loading gauge (*minimal Lade Profil*).

A loading gauge applicable to the whole network of the Union was decided on at the conference of *Mayence* in 1867. This template shaves, here and there, rather too closely, the *minimal Profil* of the old lines; a minimum play of 6 ins. has been adopted, and the different managements have been invited, in consequence, to modify these outlines : a result which, according to the *Handbuch für specielle Eisenbahn Technik* (*) will not be long in being carried out.

The following are the conditions of the new French Schedules affecting and limiting the cross outline of the vehicles :

Art. 7 : Width of the line, between the insides of the rails........	$4^{ft},72$ to $4^{ft},75$
Width between the lines, or double lines, from outside to outside of rails..	$6^{ft},56$
Width of the side spaces, or distance from the outside of the rail to the top edge of the ballast................................	$3^{ft},28$
Art. 11 and 15. Width between the parapets of viaducts under the line, at least : for double lines................................	$26^{ft},54$
And for single lines...	$14^{ft},76$
Art. 12 : Opening between the piers of over-bridges, at least....	$26^{ft},24$
Clear height above the outside rail of each line, at least.........	$15^{ft},75$
Art. 16 : Width between the abutments of tunnels, at the level of the rails, at least..	$26^{ft},24$
Height of the arch above the level of the rails, at east	$19^{ft},68$
Height from the top of the outside rail to the intrados, at least...	$15^{ft},75$

Stipulation No 16 (2) provides a reservation in the case of works already approved of, which are not to be subjected to a retrospective effect.

The distance between the rails of a main-line, and the works, or obstacles

(*) 1st Part 1869. *W. Engelmann. Leipsic.*

of any sort, is not thus completely defined by the schedules, but it results implicitly from the other stipulations. This point, which particularly affects the safety those who work the trains, has been regulated on the "Paris and Méditerranée" system, by an order dated the 24th September 1868, modified in accord with the control department, and approved of by the Minister of Public Works. It will be useful to give it here :

The regulation distance required between the outside edge of the rail, and the works established along a main line, is not the same on all the lines of the P. L. etc. system.

It varies with the schedules which determined the conditions under which these lines were established, before they were united together.

The oldest schedules specified this dimension and fixed its minimum, in some cases at $3^{ft},28$, in others at $4^{ft},10$. The more recent schedules are less explicit on this point. They limit themselves to determining on the one hand, the space between the lines, and on the other hand, the minimum width of the railway between the piers of the bridges and tunnels, as well as between the parapets of viaducts; from this follows implicitly, the minimum distance from the rail to the works along the line.

In short, this distance varies between considerable limits : from $3^{ft},28$ up to $5^{ft},00$.

It should be remarked, that the smallest of these figures, does not leave enough room for a platelayer to get out of the way on the side-space, and also does not allow for the doors that might happen to get open during the running of a train. It is impossible for us however to reconstruct our works on certain lines, particularly the tunnels, and the administration itself has declared, by accepting stipulation No 16 (2) of the joint schedule, that it had no intention of inforcing any such thing.

But besides the usual works, isolated obstacles are met with along the railway, such as telegraph-posts, lamp-posts, signal masts, not forming part of any submitted and approved plans, being besides, for the most part recently put up, and to which stipulation No 16 (2) is not applicable.

Now it is precisely these isolated obstacles which are the most dangerous, if not for the work people passing along the line, at any rate for the drivers when they have to look out from their engines.

It is thus the safety of the drivers, and solely of the drivers, which is the ground for the present circular (*).

We have seen higher up that by adopting the varying figures of the schedules, there would not be, in many cases, a sufficient clear space.

— On the other hand, it would be a great simplification in practice and a guarantee of exactness in execution, to have only one single formula for all the lines. This is why we have thought well to investigate, independently of the clauses of the schedules, what was the

(*) This meausre however affects also the other persons engaged in working the trains, and also the passengers who might have occasion to make use of the communication by means of the long steps, in face of danger.

Authtor's note.

distance really necessary between the rail of a main line and the adjacent obstacles; and we definitively decided on the figure of $5^{ft},43$, which is, besides, often met with on existing works. This distance of $5^{ft},43$ allows of a door being opened in a running train, and also allows the driver to keep on the foot-board of his engine and lean his body over $1^{ft},47$ beyond the outside edge of his foot-board.

It needs scarcely be said that this figure is a minimum, which should always be increased, where possible.

On the preceding considerations, we have decided to adopt the following arrangements.

1st. In future no *isolated obstacles*, such as telegraph-posts, gradient boards, signal-posts, and so on, must be put up *permanently alongside of the* line, at less than $5^{ft},43$ from the outside edge of the rail unless, however, the obstacle is not more than $1^{ft},0$ above the rail, or is altogether $14^{ft},76$ above.

All the isolated obstacles, previously placed along the line at a less distance must be set back, within the shortest possible delay, to a distance of $5^{ft},43$.

2nd. The same thing ought to apply, in general, to the isolated obstacles permanently set up in stations. At the same time, exceptions may be admitted as regards obstacles, on which for example are placed switch-signals, when it is practically impossible to do otherwise; but the distance must be brought up to the $5^{ft},43$, whenever modifications are made in the station arrangements.

3rd. The foregoing regulations apply only to main lines, and lines run over by engines. Along goods lines and sidings, even when open to engines, isolated obstacles may be brought, according to circumstances, close to the distance of the gauge (Pl. X, fig. 17) ($2^{ft},70$ from the outside edge of the rail), when it is practically impossible to do otherwise.

4th. In the case of works going on, on the line and in the stations, *temporary works*, such as centres, scaffolding, and so on may be, where it is impossible to do otherwise, set up at less than $5^{ft},43$ from the outside edge of the rail, without however going within, in any case, the loading gauge, at any point of its perimeter. In such a case, the Engineers should previously draw up a memo., setting forth the exact distance along the line of the proposed temporary work, and its distance from the rail. This memo., which should also mention the date of the commencement of the work, and its probable duration, should be transmitted to the traffic and locomotive departments, who should aknowledge the receipt thereof.

5th. In urgent cases, or if it is only for a very short time, the Engineers will advise, directly and in writing, the heads of changing stations, on both sides of the momentary pressure on the traffic, in every direction from which trains can arrive.

They ought equally to give notice to the superintendent of traffic on the section where the work is proposed.

6th. Provided that the temporary work in no way incroaches over the loading template, no other precaution, no notice will be required as regards the passengers by the trains.

In all cases, the controlling engineers (*) should be supplied with a copy of the memo.

(*) Of the Government Railway Department. There is a much greater interference on the part of Government in France, in the construction and working of railways than with us. *Translator's note.*

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n the case of clause No 4, and directly by the engineers in charge of the road, in the case of clause No 5.

8. *Application of the load to bearings outside the wheels.* — The bearing-springs, no less indispensable on railways than on common roads, ought to be placed as near as possible to the wheels which directly undergo the reactions of the rails, that is to say, upon the axle-boxes. They ought also, for the sake of the axles, to be placed near the points of support, that is near the naves of the wheels, either inside or outside.

The second position, much more convenient for lubrication, offers two notable advantages, one as regards stability, the other, as regards resistance to traction :

a. Stability. The distance between the rails fixes the breadth of the base of support of the whole vehicle ; the distance between the bearing-springs, fixes the width of support of the body.

The function of the springs is to give way, storing up the work of the shocks. The amplitude of the changes thus produced in the form of the spring, followed by a return to equilibrium, after a series of oscillations more or less protracted, varies at the same moment from one spring to the other; so that the body is inclined over, first to one side, and then to the other. For the same relative depression of the two springs of one axle, the transversal inclination of the body, is so much less, as the distance between the springs is greater. It is therefore very useful to increase the width of the *elastic base.* On the other hand, the springs being brought under the side soles of the frame, there is no bracket or other arrangement necessary to carry the springs.

b. Resistance to traction. The body of the axle, that is to say the portion comprised between the wheels, is submitted to strains which vary according to the nature of the line, the speed, and the state of the permanent way and stock, and are often considerable; from which the prolongations of the axle outside the wheels are free. These strains, to which we shall return, when treating specially of the axle (81), are the torsion due to the solid connection of the wheels, and, above all, the pressure of the rails upon the flanges. The diameter of the body of the axle ought to be sufficient to resist these strains, as well as the permanent load, and the shocks conveyed by the guard plates, while the outside journals having only the load and these shocks to withstand, may have a much smaller cros-section.

9. *Number of, and distance between the axles.* — Leaving on one side American stock, in which the number of the axles depends mostly on the nature of the line and the state of the road (14), railways carriages have generally only four wheels. In France, six-wheeled carriages are only to be found on a portion of the " Méditerranée " system; in England, the *Great Western* is the only line which appears to still adhere to them, to a certain extent, and the opinion of engineers is now very little in their favour. In Germany, these carriages, relatively very numerous at the outset, are becoming fewer daily. They still predominate in Prussia, however, where they numbered, in 1867, 2 241 with six wheels, to 1 098 with four wheels, but this ratio is rapidly diminishing. Out of twenty-four managements, giving an opinion of the relative values of the two types of 4 and 6 wheels, at the meeting at Dresden, only three were in favour of 6 wheels : bodies divided into 4 or 5 compartments, and borne by only two axles, obtained almost complete unanimity.

In principle, six wheels may be warranted by the great dimensions of the vehicles. If the load cannot be taken by two axles only, on account of the diameter of the journals, a third axle is evidently necessary.

If the transversal dimensions of the carriages are limited by those of the works of the formation level of the line, there is no restriction as to length. By increasing that, we reduce, for a given train, the number of couplings, in the same way that with long rails we diminish the number of joints; but beyond a certain limit, special appliances become necessary for running on curves, even of ordinary radius (172 and following), and these appliances have, among other disadvantages, that of rendering the vehicle but little fit for travelling at high speeds. Or the points of support may be grouped together towards the end of the frame, as in the American stock, which presents in a high degree that disadvantage; or, indeed, they may be spread under the frame, more or less uniformly, and then the division of the load amongst them is subject to great inequalities, in consequence, either of sudden changes of gradient, or of accidental irregularities of the road. It is useless to insist more fully, here, upon the observation already made (I, 220) on a particular case. Let us only add, that if the uniformity of the loads on the axles can be obtained by coupling the springs together by beams, as was done long ago, in the six-wheeled carriages of the State line in Bavaria, that arrangement has been rarely copied. The beams, however, as will be seen farther on, play a very useful part in locomotives. They are equally much employed, in the United

States, for tenders : but they are a complication in no way justified for carriages.

In fine then, the length between the buffers rarely exceeds 26^{ft}, 25 in the carriages in use on the great lines. We shall point out the principal exceptions, and the more or less valid motives upon which they were made.

But it has been desired independently of all considerations of load and dimensions of bodies, to justify the preference given to six-wheeled carriages, by considerations of stability and safety. It is thus that in France, they have got introduced on the line from *Avignon to Marseilles*, the first section worked, of the great line from *Paris to Nice*; and the same type has extended over the whole of that great artery, while four-wheeled stock was adopted for the "Bourbonnais" line, and for the branches of the system.

Do the six-wheeled carriages really possess the advantages of steadier motion, and of greater safety, which are now and then attributed to them? If these advantages were real, one ought to suppose that the numerous companies who persisted in employing carriages with two axles, would have yielded to facts, and instead of being reduced in number, the use of this type would have been generalised.

In the first place, as to stability, steadiness of motion, the element that has the greatest influence on these is the distance between the extreme axles. The longer, more massive a carriage is, the more the overhanging portions beyond the axles are reduced, and the more stable the carriage is. If all else being otherwise the same, an intermediate axle be added, what will be the effect of this addition? Evidently to diminish the stability. The resistance to the swinging movement, which consists particularly in an oscillation of the vehicle round the vertical axis passing through its centre of gravity, is so much the greater, the more the end axles are loaded, seeing that the moment of the transversal friction is so much the more increased. Now the intermediate axle reduces this load, and consequently, the corresponding friction. On the other hand, the frames tend to become "hog-backed," from the overhanging portions at the ends. The reaction of the intermediate spring only aggravates this effect. It is true that this consideration is more applicable to goods-waggons than to passenger-carriages, in which the overhanging portions are much less, precisely with a view to stability, and the frames of which, are besides much less loaded.

From the point of view of stability, the advantage would be rather in

favour of the four-wheeled carriages. And, in effect, no one would pretend that the movement is steadier on the *Paris and Nice* line, than on the other lines which run at an equally high speed, and with the permanent way in equally good order, and rolling-stock with a great wheel base, such as the Northern, the Eastern, the Western, the *Orleans*. The third pair of wheels of the " Lyons " stock, is its object a more considerable useful load? Not certainly now for the second and third class carriages. If the first class carriages of the " Méditerranée " line, with three compartments and a coupé, contain four places more than similar carriages on the other French lines, the actual carriages of the other two classes contain the same number of places, on all the lines : respectively, forty and fifty seats.

As to the question of safety, it may be maintained, with some show of reason, that if an end axle or tyre breaks, a carriage with six wheels will have a better chance than the others, of being held up by the couplings, which will thus have less strain on them. Admitting this advantage, it is clear, on the other hand that the additional pair of wheels introduces all the chances of accident incidental thereto, and which, if they be diminished by the central position of the axle, are nevertheless real; and it may be therefore fairly doubted that there is any advantage on the score of safety.

To add a third axle, is to increase uselessly, by 50 per cent, the number of axles in a train; and this means increasing the expense, the dead weight of the wheels, and the chances of accident inherent to these parts.

As the acquirements of the traffic service are such as not to call for, in general, the adoption of types of carriages, the weight of which exceeds what can be carried on two axles, it is much better to adhere to that number, adopting at the same time, as great a length as possible between the axles; and the easy curves of our great lines, fortunately allow this to be carried to the fullest extent required for steadiness, even at a high speed. On the " Nord ", which presents, in this respect, the most favourable conditions, this has been pushed to the utmost limit. The spring-clips (70) are fixed to the end transoms, and the distance between the axles thus brought to from $11^{ft},50$ to $13^{ft},12$. Upon the " Eastern " of France, a more difficult line, the distance is $11^{ft},81$ for carriages running at a high speed. The orders of the traffic department are to reserve them as much as possible, for mail and express trains; and only to put them into ordinary trains, from want of others.

It is only with regard to certain appliances introduced with the view of running on very sharp curves, that the third axle presents perhaps, some advantages, as will be seen (183), and after all, these advantages have been

over strained. As to ordinary curves, which require no particular contrivances, experiments made in England, seem to show that with equal distance between the end axles, the intermediate axle notably increases the resistance due to these curves.

The Dresden meeting has fixed the maximum distances as follows:

Curves, on main line, from	800ft to 1000ft	....	12ft,00
» »	1000ft to 1200ft	....	15ft,00
» »	1200ft to 1500ft	....	16ft,50
» »	1500ft to 2000ft	....	18ft,00
» »	beyond 2000ft	....	24ft,00

These wheel bases, relatively very considerable, are only applied to passenger-carriages.

In Prussia, the figure adopted for passenger-stock is 15ft,91; this has been far exceeded on the Eastern of Prussia, on which six-wheeled carriages, with distance between the end axles of 23ft,18 pass through crossings with a radius of 520ft. On the Rhine Netherlands line, on which the curves are all of large radius, the distance is carried to 22ft; carriages over 33ft long are put on two axles; the second class bodies, divided into seven compartments, contain 70 places; the load on the rails is as much as 7tns,5 on each axle: this is however, only a question of journals.

It may be at once added, that for goods-waggons, it is recommended in Germany, not to go beyond 10ft, unless in the case of certain waggons for special purposes.

In general, a great distance between the axles cannot be allowed in the case of this stock, subjected to so much shunting, passing through sharp curves, and turning on tables, which are, of very limited diameter in goods-stations (I, 299, 300).

CHAPTER II.

DESCRIPTION OF PASSENGER STOCK.

Carrying stock consists of two great divisions: passenger-carriages, and goods-waggons.

The elements for consideration are: the body, the frame, the guard-plates, the bearing-springs, the axle-boxes, the wheels and the couplings.

§ I. — **Bodies.**

10. The plan of this work does not comprehend particular details of construction; which, in spite of their importance, belong rather to the art of carriage-building, than to engineering. But the manner in which the carriage bodies are arranged and disposed, has too general an interest, and gives rise to too many wrong ideas and ill considered objections, for this question to be passed over without some considerable notice.

The type most in use, is analogous to the old style of vehicle commonly running on roads. Divided into three completely separated compartments, with cross seats and side-doors, such were the principal characteristic of these vehicles, only that the end compartment, or "rotonde" (*) was obliged to have the seats longways, and the door at the end, on account of the size of the hind-wheels. Excepting in this last particular the same conditions appear in our railway-carriages, but greatly improved as regards the proportion of room to each place, for the first-class, and pretty much too for the second, as regards general comfort.

Rapid as has been the progress of these improvements, they have not kept pace with the ideas of the public on the subject, a dead set has moreover been made, over and over again, against the principle even of the existing type, condemned not only on the score of comfort, but of safety.

Against this type, characterised by the separation of the passengers into small groups, located in separate compartments, without intercommunication, has been set up the system known as: *American*, characterised by an interior communication not only right through each body, but from one

(*) This refers to the French diligence. *Tr*

body to the others, and consequently through the whole length of the train. The introduction of this system on some European railways (on the Wurtemberg, and part of the Swiss lines, the Austrian, which by the way has given it up for some years), has enabled passengers to compare the two; but such a very superficial comparison, not going beyond appearances, made no allowance for the radical difference in the conditions; opinions were laid down without perceiving that in holding up American stock, were sacrificed to accessory and accidental advantages, those of quite an other importance, to which the European public essentially adheres, and with very just reason. It is the freedom which that stock allows passengers, which has led opinions astray. This is quite easy to understand; and at the same time, the truth being, that that freedom, in the few applications of that stock in Europe, is far from being absolute, and becomes daily less so, through indispensable regulations. The passenger is only, in reality, free within the compartment he is occupying, and if the doors communicating from one carriage to another, are opened during the transit of the train, it is as a personal indulgence, and not as a right. As to safety, European rolling-stock has been the object of an almost universal outcry, on account of some criminal attacks committed in England and in France. It has not been a question as to whether American rolling-stock really offers greater guarantees in this respect, although affording no example of similar facts. The traveller who sees novelty, is always more struck at first sight with advantages than with objections. It is quite the reverse as regards what he is daily in contact with, and which has lost, for him, the charm of novelty. This disposition is particularly prominent in the French traveller, who is prompt in judgment, and captious.

11. Let us dwell a moment on this double question of safety and comfort, taking into account a condition that no one certainly would undervalue: that of speed.

1st. *Safety. — a. From the point of view of criminal attempts.* To lay down complete safety, with respect to criminal attempts, as an aim to be energetically followed, is all well enough, but to make an absolute right of it for the passenger, without restriction, an absolute duty on the part of the Company, as well as for the Government which controls, is that possible? How is a traveller, who nowhere, neither in the street, at his own house, nor in that of others, is safe from criminal attacks, how, by what inestimable privilege of the railways, should he be completely withdrawn from all mischance, by the sole fact of his being in a train? If, as has happened, ill-doers succeed in spite of every percaution, in throwing a train off the line, the pas-

sengers are injured, who would dream of placing the moral responsibility of the disaster on the Company or on the Government? Would the responsibility be any the less implied, because the crime and the disaster are greater? It is objected, it is true, that a passenger, shut up in a compartment alone, is hands and feet tied, so to say, at the mercy of any criminal attempt; that he can be attacked while he is asleep; that if he calls for help, the noise of the train drowns his cries; that escape, were that possible, would be death; that in this helpless situation, imposed on him rather than accepted, the Companies and the Government cannot decline the obligation of protecting the traveller who confides his life to them, and who, moreover, is unable to defend himself. Admit the obligation; but like all human obligations, it has a limit: *force majeure*. Supposing a passenger, seeking to be alone (the general habit, for night-journeys, as is well known) installs himself in an empty compartment, and another, whose design nothing betrays, takes also a place therein, and murders and robs the first during his sleep, and then escapes at the risk of death, by jumping out of the train while in motion: such would most certainly be a horrible crime, especially if the culprit gets off and escapes punishment. But what is to be done? Through what contrivances of construction, by what measures would it have been possible to prevent this crime, at least to lay down the principle, that never at any moment shall two passengers be alone together in one compartment, and that at a given point, an official of the Company or of the Government, shall be introduced to protect them from each other? Such a thing has been proposed, but is it practicable? And if, out of three passengers, two are accomplices? Who would go off to sleep under the eye of an official? Who would not infinitely prefer to feel himself less protected, and willingly besides accept the risk, small as it is? Passengers of course like to be sure they are safe, and they are right. But they also like to install themselves as commodiously and comfortably as possible, to keep away from each other, at night especially; and they are not wrong in that either. The sensation evoked by a crime is violent, but often exaggerated, and consists, a good deal, of talk. People make a fuss for some days: and then admit that such a crime happens but very seldom, and is attended by peculiar circumstances, and at any rate, is not likely to occur again in a hurry; that crowded compartments are very objectionable; and they get away therefrom if they can, and quietly go off to sleep. Would the interior passage be indeed any safeguard when passengers, sparse and spread about, are asleep in a winter's night, when the visit of the guard, who has found all right and shut the doors, allows the criminal to make sure of the few minutes necessary to be

alone with his intended victim. The passage itself, with its convenient side steps, does it not provide the culprit with far readier means of escape, than European stock?

From the point of view of criminal attempts, the one type is as good as the other; to urge that point any farther would be idle.

b. From the point of view of train accidents. — As to safety looked at in a more general and more serious manner, that is to say, as regards certain accidents due to the rolling-stock, the interior communication offers, admittedly, guarantees which the separate compartment system has as yet failed to offer. Fire breaking out in a compartment, an axle, a wheel, or a spring giving way, a carriage running off the line, place the passengers in a most critical position, because their cries, their signals of distress, all their efforts to call the attention of the guards, may remain for a length of time unheeded. Although such accidents are rare, they do happen, from time to time; and that is, of course, grounds as is asserted, for some step to be taken in the matter; but does that mean, that the type of stock which best answers the convenience of passengers, and requirements of the train service, should be given up? It would seem, at first sight, that everything could be reconciled by combining, with compartments, the addition of a side passage. In that way the matter has been settled in Russia (21). It has been sought also, as will be seen presently, to carry out the same thing in France, but saddled with conditions involving practical impossibilities, made more insurmountable here (*), on account of the loading gauge, which must be duly adhered to (7).

It is essential, we all know, that passengers should be able to call the guard's attention promptly and surely, in case of accident, and thereby apprise the engine driver. But that is a question of signals, and not of rolling-stock. Nothing is simpler in appearance than carrying this out. Electric currents particularly, seem to be specially indicated. When it is so easy to communicate at one single stretch, between Paris and Bordeaux, Paris and Marseilles, what a trifle it must certainly be, to form an electrical communication throughout a train, a length at most of seven or eight hundred feet! Unfortunately, it is by no means a trifle. It is even indeed, a very serious difficulty; so serious, that notwithstanding several lengthened trials, and the high expectations entertained on the subject, it is still a thing of the future.

(*) In France, of course. *Translator's note.*

Later on we shall return to this point, and shall at present content ourselves with the single remark : if it is difficult to establish a perfect communication throughout the very small length of a train, while it is easy to communicate many hundred miles at a stretch, it is that, in the second case, the metallic continuity and consequently the conductibility is perfect; while in the first case, the continuity from carriage, by simple contact, is uncertain and subject to a number of risks. A few grains of sand, a little grease, coming in the way, and there is an end of the current. This is doubtless only a question of purely practical difficulties, which are however the most serious. In any case, a railway-train is not an apparatus for experimental physics.

12. 2ndly. *Comfort.* — A tourist returning from *Berne, Zurich, Fredericks-haven*, is delighted with the country, and with the railways. The one seems, in fact, to be made for the other. For the leisure traveller who journeys in daylight, and who, in the evening gets under a good roof to wait for the next morning's train, nothing could be pleasanter. The long bodies of the second and third class carriages, airy, and with plenty of openings, allow him to change his place, and his point of view : we shall come back to the first class just now. Thanks to the wise slowness of speed, he loses none of the beauties of the country. Sometimes, even, when the conductor is considerate or interested enough to allow him to get on to the end platform outside the door, what can be nicer? And to fancy that England, France and Germany are so behindhand, as to submit passengers to an odious *quasi*-cellular system ! How many times, also, has not the Swiss stock been *discovered* and been revealed to the Companies at home, who will persist in a turning a deaf ear thereto !

As to the first class carriages, little used excepting by foreigners, there also a sacrifice has been made to the desire for retirement : they form small saloons of six or at most eight places; and passengers from the other classes are not allowed to pass through them. But leaving the first class aside, which is right, Switzerland or France? Both. In Switzerland the distances are short, the population patient, and not much in a hurry. Foreigners themselves, when they crowd into the country are at leisure, and do not pay much attention to speed. There is no night service of trains. In the day-time, when the weather is fine, the country picturesque, the traveller is in ecstasies with the freedom of moving about, and sometimes, too, of passing along from one carriage to another. But let the weather

come on bad, these advantages quickly lose much of their value. What would it then be, during the long winter nights? The enthusiasm would be remarkably cooled down, and would soon give place to bitter and well grounded criticism. This sort of rolling-stock, praised during the day, would be abused when night came. Must there, then, be *two* sorts of rolling-stock, one for day, and the other for night? The big second class compartments are supplied with simple straight seats, poorly cushioned, like those of the mixed carriage of the "North Eastern" of Switzerland, shown by *figs.* 7 and 8, Pl. I; an arrangement not much conducive to sleep. As to the first-class places, if they are more commodious, that is, I maintain, because like ours, they are arranged in small compartments closed off from each other, which the guards often keep under key.

13. *Fastening of the doors.* — Let us remark, in passing, that the fastening of the doors may be considered as a guarantee against criminal attempts. It might prevent the crime, because it would prevent either the access or the escape of the culprit. But it will be remembered with what force public opinion was raised, in consequence of the *Bellevue* disaster (Versailles, left bank), against that imprisonment of passengers; and the public most certainly was right. The advantages of fastening the doors are nothing compared to the inconveniences caused thereby; and we have every reason to be surprised that it should still be in force, in that country, where everything that approaches anything like an encroachment on personal liberty, is so impatiently put up with, and where therefore such a step should be particularly obnoxious, that is to say, in England. The bars across the window-openings, often required where the clear space of the line is obliged to be reduced, may be allowed; but locked doors are too much (*).

It is true that some travellers, find their advantage in this; getting compartments to themselves (always to be by themselves) by means of small financial transactions.

In France, the object of fastening the doors was to prevent the danger arising from people getting out before the trains had come to a stop. The guards locked the doors as the trains started, and opened them at the next stopping station. But after the "left bank" accident, this step was given up; and it was blamed with more or less reason for having aggravated the horrors of that awful occurrence.

(*) The English railways generally, now, lock only one door, that farthest from the platform. *Translator's Note.*

It was, at the end of 1868, in England, the object of no less violent criticisms, with reference to a serious accident: the collision of an express-train, with waggons loaded with petroleum, which had become detached from a train going in the same direction, and running backwards down an incline, dashed into the engine of the express-train, and set fire to the train. The aggravations of the consequences of the accident, by the passengers having been locked in, seem to be better established in this case than in the preceding.

In the carriages of the type usual in Europe, the side-doors are multiplied as much as is requisite. The longitudinal passage does not, it is true, exclude these doors, but it permits them to be dispensed with; and that is what is done, with greater reason, that their suppression allows the body to be made broader (7, 15). But the access to the carriage is only then possible at their ends; so that for these very long carriages, and at times when there is a rush of passengers, the entrance and exit of the passengers requires a great deal of time. The two streams of passengers, the one inwards, and the other outwards, which take place at each end, increases this drawback, which is however partly set off by the easy access which the small platforms with steps at the ends, give. The foot-boards of our carriages are inconvenient and even dangerous, especially when passengers have to descend in the dark, from carriages at the end of a train extending beyond the platform, and thus to step down a height of $1^{ft},64$ to $1^{ft},97$ (Pl. II, *figs.* 3 to 8).

14. *American rolling-stock.* — Rolling stock with longitudinal passage is applied, in America, under conditions very different in many respects to those Switzerland presents. The distances are often enormous, night journeys most common, which does not prevent the type to which America has given its name, maintaining its place there, as it is justly entitled to do. In the United States, as in Switzerland, and more than in Switzerland, is that rolling-stock perfectly in its place; but on very different grounds.

This rolling-stock had not, so to say, to be invented, so much was it evolved, quite naturally, out of the particular local conditions, and so perfectly appropriate is it to the manners, to the quite special requirements of working the traffic, to the nature of the lines, to the state of the permanent way. And precisely because it is so perfectly suitable to America, would it in no way do for our European lines, where every thing is different, not to say the reverse. The question is complicated, and should be treated with some fulness. In this case, the arrangement and dimensions of the body, cannot be investigated

completely apart from the special disposition of the vehicle carrying it.

What at first strikes one in this rolling-stock, is the great length of the carriages; now this length itself (as at first seems singular) is frequently the immediate consequence of the sharpness and multiplicity of the curves.

This dependence is easily explained. The principle of American stock is not, as has often been said, the free convergence of the axles; on the contrary, it is the rigorous parallelism in each group of two, and sometimes of three and four axles (Pl. VIII, *figs.* 10 and 11); but at the same time, a parallelism combined with a means of turning, so that it opposes no obstacle to running on curves.

In the ordinary carriages, with eight wheels, the distance between the parallel axles is very often only $3^{ft},28$ (Pl. I, *fig.* 9) and rarely exceeds $6^{ft},56$. A vehicle carried by two axles so close together, could only have, even overhanging excessively at the ends, in the double respect of strength of frame, and stability, a length and consequently a capacity altogether insufficient. This led to placing the carriage on two pairs of parallel axles, but fastening the general frame to each pair, only by a turning-pin, round which each of the groups can turn, as much as the action of the flanges requires in a curve.

Each vehicle having thus at least eight wheels, it was necessary, in order that each of these should carry its proper load, to give the carriages a capacity and consequently a length, about double that of four-wheeled ones.

This great length gives besides for the carriages of that system an advantage already pointed out in principle (9) but more marked in this case. The interior platforms p, p, with lateral steps m, m, m . . . . (Pl. VIII, *figs.* 10 to 12), required by the central passage, form a constant for each body. The excess of length and of weight corresponding, would thus tell twice as much on our short carriages, as on American carriages of double the length.

Carriages with the frame fastened only by turning pins to trucks in which the axles are fixed, suit for low speeds, upon roads of light calibre, badly maintained, and out of level. The nature and state of the permanent way would be sufficient in themselves, to render a contrivance of this sort necessary. The trucks can tilt, accommodate themselves by their four or six points of support, and spread the load amongst them, without the body participating in the movements. This independence of the trucks, cooperates very efficiently, then, in that respect, with the action of the bearing-springs; but the system is inadmissible even with the most excellent permanent way. The freedom of the trucks to horizontal oscillation round their turning pins, placed, in rolling-stock truly American, in the centre point of the truck, to be symmetrical, puts the vehicles into conditions of sta-

bility greatly inferior to that of carriages with their axles fixed directly to the frames. The oscillations aggravated by the conicity, often very great, on account of the curves (as much as $\frac{1}{7}$), react necessarily on the bodies; and it would be the same, even if recourse were had, for the purpose of establishing between them a certain amount of solid connection, to the contrivance of the coupling with buffers under pressure (126), often in this case besides, inapplicable, on account of the size of the angle formed by two very long carriages on a very sharp curve, and of little efficacity in any case, for if it establishes a certain amount of solid connection between the bodies, it does not restrict the freedom of oscillation of the trucks.

Great sacrifices have been made on the great European lines, to avoid sharp curves and stiff gradients, to establish the works and the road solidly, to put, in a word, these lines into a condition which allows of a very high speed, which is daily more and more insisted on. To introduce on lines of such costly perfection, rolling-stock which of itself excludes speed, would certainly be a deplorable fallacy.

But in the United States, there are still farther grounds for the use of this sort of rolling-stock.

Our railway-stations, so complete in their arrangements, are quite wanting in America. There, they are generally reduced, excepting at important towns, to what is strictly necessary for the service of the line; and they are only stopped at for the time required for the trains, and watering and cooling or changing the engine. Thus a sufficiently effective mean rate of travelling is realised, in spite of the limit put to the speed by the flimsy style of road, and also, as we have said, by the construction of the rolling stock itself. Under such conditions, thoroughly appreciated at the same time with regard to the prompt and economical carrying out of the immense network of lines there was to construct, a train has to be every thing in itself. Travellers must find therein, as on board a steamer which makes but few and short stoppages, every necessary of life, with something more; what indeed they find with us, in a more complete way, in our commodious and costly stations. This has become particularly indispensable, now that trains run right across the American continent, and make regular long voyages from one ocean to the other.

An easy communication throughout the whole extent of a train, is not then, in the United States, a question of comfort, still less a matter of safety. It is a necessity. It is, besides, of easy application as regards control, for as yet there is generally only one class of passengers, ex·epting in the saloon carriages, which will be noticed presently (33).

15. *Composite systems.* — We are not bound, of course, to take American rolling-stock in its entirety. The mode of arranging the places on the one hand, and on the other the two articulated carrying frames, and the great length of the body, are independent features; one of which may be adopted, without the other. This is what has been done on some of the Swiss lines (North East), and of the German lines (Wurtemberg, Bavaria) (Pl. I, *figs.* 7 and 8; Pl. V, *figs.* 1 and 2); and in France on a small line from *Lyons to Bourg* by way of " *the Dombes* " (Pl. VII, *figs.* 12 to 15, and Pl. VIII, *figs.* 1 to 7). The stock recently built by the *Méditerranée* for the lines in Algeria, comes under the same category.

The trial in Bavaria, restricted to third class carriages, was not followed up. On " the Dombes " line, which is very short and has no night service, the application of the arrangement was attended with little disadvantage, although not otherwise warranted. The relative dead-weight is exaggerated on account of the space lost; the length of the trains is notably increased by the application of end platforms to short carriages; but as the speed is low, these disadvantages are less felt.

The application made on the Algerian lines is better grounded (Pl. III, *figs.* 1 to 10). If there was no reason for adopting the great American eight-wheeled carriages, it is incontestable, that large compartments with numerous openings, through which the air can freely circulate, are perfectly in keeping with the climate. On the other hand, the interior communication was an indispensable condition where simplicity of train service was a main feature. The trains took up and set down the passengers at simple stopping-places, the guards themselves gave out and collected the tickets, and have thus to be incessantly passing along the carriages, so that they are always as it were in the middle of the passengers. Under these circumstances, the disadvantages inherent to the interior communication, have to be put up with, that is to say: 1st lost space, to the extent of nearly 20 per cent, and 2nd the increase in weight and length, from the outside platforms.

The bodies of the Algerian carriages are very broad : 9^{ft}, 84 at the level of the seats, that is to say 0^{ft},65 more than the broadest of our usual carriages (23). This excess of width possible so long as no spaces have to be provided for doors, allows four places per seat, in the first and second classes (*figs.* 1 to 5), and five in the third (*figs.* 6 to 10), in which consequently the passage is not in the centre. The frame being the same, the second class places have as much room as the first; and only differ therefrom by the cushions. This is an imperfection; but, in Alge-

ria, first-class customers are little to be counted on, and are generally holders of military tickets, at quarter fares. Passengers are not allowed to go from one carriage to another : the result of course of the difference in the classes.

16. Four-wheeled rolling-stock, with longitudinal passage and end platforms, has been adopted on the line from *Berne to Lucerne*, in accordance with a design which had for object to retain the advantages without the disadvantages of the American stock. But if some of the latter have disappeared, others have been added to, particularly the greater influence of the end platforms on the weight of the train. It must be admitted, at the same time, that these considerations, like that of the loss of internal space, have much less importance on secondary lines, where the velocity is always low, than on the great lines running at high speeds. Only, it may be asked, whether the American rolling-stock, pure and simple, would not thus be preferable, to this compound system, neither rejects nor retains anything offering serious drawbacks, excepting for very fast trains, unless however, that inseparable from the great size of the vehicle, when one carriage has to be added to a train, for the accommodation of only a small number of passengers.

17. The longitudinal arrangement of the seats seems to be often preferred to the cross way. This arrangement, adopted in the first type of third class of the Northern of France, seems to be a natural consequence of the access at the ends; it allows the space to be better utilised, by putting two seats in the middle, with one back between them. It is true, that when the passage is employed, it is kept as much as possible clear as a thoroughfare; and it should not be interfered with, nor taken up by passengers' feet.

18. In some exceptional cases, the English and American types have been combined together, in another form : from the first, has been taken the arrangement of the bodies, that is to say, compartments with side-doors; and, from the second, the articulated bearing frames. It is clear that this step could only have arisen on a line with very sharp curves. On this account, it has been adopted on the South era and Western lines of Queensland. The first-class carriages only contain twenty-eight places on eight wheels. But as the gauge is only $3^{ft},50$ (I, 15), the length of the bodies is relatively considerable, and the proportions approximate to those of the American system, of which indeed this is, as it were, a reduction.

19. Another program can be adopted : the combination of the advantages of the two types, that is to say, the longitudinal passage, placed at the side, with compartments and side-doors.

This program can be carried out : 1st. by sacrificing one place on every cross seat, 2nd. getting the width of the passage, by a slight encroachment on the places, kept to the same number, by taking off some of the thickness of the sides of carriage, and by a little increase in the external width of the body ; 3rd by making this condition the starting point of the whole system, and adopting in consequence, as has been done in Russia (Pl. I, *figs.* 9 to 11, and Pl. VI, *figs.* 1 to 10) a broader gauge, and wider loading gauge.

Some persons have been led astray by the first solution, which they have looked on as simple and quite practicable. As on the average, in trains more than a quarter of the room is not utilised, it is quite fair to infer that that quarter may be altogether dispensed with.

If averages mislead, and their abuse is dangerous, it is certainly in such a matter as this. The expresses, on certain lines, and at certain periods of the year, are very often full. To take away a quarter of the places, the number of the vehicles must be increased by a third : and thus we arrive at impossible weights. Very well, it may be said, but why not work with double engines, or increase the number of trains? That is soon answered. What railway people ought to know, if the public does not, is, on the one hand, that trains with two engines must be prohibited as rigorously as possible, with fast trains; on the other hand, that trains in general, above all these, cannot be multiplied beyond a certain limit, fixed by considerations of safety, and also for the sake of economy, which has to be considered.

It will be seen just now (27), that, leaving on one side certain special types applicable to short trains, the weight of carriages, per place, has always gone on increasing, on account of the improvements introduced into ordinary rolling-stock. It certainly would be impossible still further to increase it in the enormous proportion required for the introduction of the interior passage, and all with the view of usefulness at least very restricted of extent.

20. 2nd. A French engineer, M. *Leprovost*, has tried the second solution. A carriage constructed on this principle, has been run in divers trains on the "Eastern" of France, and the experience thus obtained thereof, has fully proved that the author has not solved the problem he undertook, that is to say, to find the place for the passage, without exceeding the regulation limits

of cross section, without reducing the number of places, and without interfering with the comfort and well-being of the passengers. With a reduction in the thickness of the sides of the carriage, carried out by the use of metal, and an increase in external breadth, not exempt from danger, the designer has been obliged to fall back on a reduction in, and a deformation of the space allotted to each passenger, (fig. 10), at the expense of convenience.

The best proof of the imperfection of the solution in question, from the point of view of comfort, is that this specimen has only obtained, during the whole of the trials, the sort of success sure to follow anything novel, a success of curiosity. Pretty well sought after in the suburban trains, this carriage was deserted on long journeys, and the passengers who hurried to get into it, got out of it with equal haste. On the subject of the dangers, to which the excess in the width of the body of that vehicle, expose the passengers who are so imprudent as to put their heads out of the window openings, it is stated in the report by M. *Goulhot de Saint-Germain*, on a petition presented to the Senate by the builder, that passengers exposed themselves "on account of their imprudence." Doubtless; but is it not natural, indeed necessary to protect the public against its own imprudence? Is it not what is constantly being done, and on railways more than anywhere else? Is not this imprudence a source of dangers, in another way as serious as those which are sought to be remedied by means of the inside passage, which may, besides quite as likely aggravate them as reduce them?

21. The line from *St. Petersburg to Warsaw*, and to the Prussian frontier offers several examples of the partial or total combination of the interior distribution of American bodies, with the ordinary arrangement of the vehicle, properly so called, and the absence of communication between the carriages. Pl. VI represents on a scale of $\frac{1}{100}$ in elevation, and to double that scale on plan, five of the types in use on that line. What results more particularly from an investigation of these deficient dispositions, is that, in the trials which they have undertaken, and which have not yet resulted in the adoption of any definite types, the Engineers seem to have thought little of economising space, for the first class especially, excepting in the type of composite carriages (*figs.* 7 and 8) in which the first class is arranged just like our own.

In the three others, the ruling idea has been to combine these two features : isolation, and interior communication having among other advantages, that of allowing access to a W. C.

In two other cases (*figs* 4, 5 and 6) the doors have been made to open,

not into the compartments themselves, but into cross passages K, K, an arrangement which may have originated in the severity of the climate, but which greatly increases the loss of space.

The second class carriage (*figs.* 9 and 10) is divided into six compartments, each having two doors, notwithstanding the communication extending throughout the whole body; it seems as if an advantage would have been gained by reducing the number of doors, as has been done in the two large compartments of the second class of the composite carriage (*figs.* 7 and 8). It is true that the side passage is very narrow, and only just sufficient to allow of an access to a W. C., or to a stove.

Altogether, the examples of the arrangements taken from *St. Petersburg and Warsaw* line, are not without interest; but therein are looked for, in vain, the elements of a design for duly modifying the rolling-stock of our great lines. These arrangements make too little of economy of space, and they are more or less in keeping with the requirements of a rigorous climate.

22. Carriages of very great length, which in the United States, were derived in a manner necessarily from the conditions of the problem, are sometimes also adopted, in other cases, and keeping at the same time, the division into compartments. Such are the new carriages of the *Metropolitan* of London, weighing empty 16 tons, and containing forty-eight to eighty passengers according to the class. They have four axles, but at equal distances apart, instead of in two end groups as in the American rolling-stock, with which these carriages in question have nothing in common, save the great length of body and the number of wheels. Their principal advantage already quoted, is the reduction of the number of couplings, and consequently of the length of the trains. They have, moreover, the drawback of being unable to be turned excepting on tables of excessive diameter. The American carriages, which can, at a push be turned on ordinary tables truck by truck, are in this respect preferable to the *Metropolitan* and similar carriages. It need hardly be said besides, that a special appliance is necessary, on account of the great distance between the end axles, for passing through curves. We shall come back to this point (172 and following).

§ II. — **Recent improvements effected in the bodies of ordinary rolling-stock.**

23. *France.*—Far superior, for a long time to the English carriages, the French were far behind the much more spacious ones of the German railways. If the English accepted without complaining, and with very good reason, our rolling-stock, the outcry from travellers from beyond the Rhine was continual, and the French carriages, which went through the whole way to Frankfort and Vienne, were deserted by passengers, as soon as they had the chance. But the *Eastern* (France) which a number of years since, earned a well deserved reputation for the care and success with which all the details of rolling-stock were carried out, under the superintendence of M. *Vuillemin*, engineer-in-chief, could not put up with that inferiority. At the present time the first class carriages of the *Eastern* (Pl. I, *figs.* 1 to 6) are $9^{ft},19$ wide at the level of the seats, and $6^{ft},81$ in height, which is in breadth $0^{ft},65$ and in height $0^{ft},29$ more than the old ones. The length of the bodies has been brought up to, from $20^{ft},23$ to $21^{ft},52$, and the increase divided among the six rows of seats. The fixed arms have been made movable round a horizontal hinge, which allows the passenger fortunate enough to get hold of a whole side, to lie down full length at his ease, and thus to possess, on a precarious tenure it is true, a bed very nearly as good as those of the sleeping-carriages of the same line (30).

The regulations of the 15th November 1846, fix for the dimensions of the place allowed for each passenger, the following minima : $1^{ft},48$ in breadth, $2^{ft},13$ in depth, $4^{ft},66$ in height. These minima are now-a-days increased, unequally, too, for the different classes, which is of course quite natural.

The following are the principal dimensions of the bodies of the new passenger-carriages of the *Eastern* of France :

	First.	Second.	Third.
	feet	feet	feet
Outside length at the seats	21,49	23,62	23,95
Outside breadth at the seats	9,19	9,19	9,19
Inside height at the centre	6,23	5,90	5,90
Inside length of a compartment	6,89	5,71	4,65
Number of seats	24	40	50

In these carriages, in the second and third class (Pl. II, *fig.* 1) always five seats on a side, the middle seat is provided on each side, with a small

pillow (0, 0, *figs.* 5, 6, 7), leaving the view out of the question, all the passengers thus have the advantage of a corner. The middle place is besides a little broader than the others, which compensates for the slight disadvantage of its position. The fittings of the second class have been decidedly improved; in the third, a small improvement borrowed from the German carriages is a real boon to travellers by night, or on long journeys : it consists in a slight curvature of the seat, and a convenient slope of the back (*fig.* 6). Thence a better distribution of the pressure, a more convenient position of the upper part of the body, and, in fine, less fatigue. Amongst the improvements of a democratic character introduced into the passenger-stock, it is well to cite the addition of curtains to the third-class carriages. The application of that useful measure, meets with a difficulty, which was of course foreseen : the frequent stealing of the curtains. It happens very often that measures of general advantage are thus paralysed, and that the mass is the victim of abuses committed by a very small minority. These thefts have, moreover, been rendered rarer, by stamping the curtains with marks which cannot be destroyed, and thus render it difficult to make any use of them.

24. *England.* — If, abstraction made of the principle, any rolling-stock could have been justly found fault with, it is certainly that of the English railways. The seats, even in the first class, were exceedingly cramped, and the really Spartan like simplicity of the second class, destitute of any vestige of cushion or fittings, was carried to such a point, that when the uncovered carriages without seats, nothing but open trucks in fact, were done away with, it was scarcely known how to arrange third-class compartments which should be inferior to the second class, and at the same time be efficiently serviceable. However, this was got over of, by depriving the passengers of air, room, and light. In these compartments, with their cramped doorways and closed-in panels, the passengers might almost look on themselves as shut up in prison-vans. For some years back, the English companies, who never anticipate the wants of the public, but who take care not to make them wait too long, have freely made large concessions to legitimate requirements.

The *London Chatham and Dover*, and the *Metropolitan*, gave the example. The second-class carriages, particularly, are lofty and spacious. At first sight that would seem to be uncalled for, in carriages where the passengers remain so short a time. But it is precisely because the passengers change every minute, because there is such a continual going in

and out, that the room and the height have to be largely measured. A considerable traffic with very short stoppages at the stations, can only be properly managed by letting the passengers have plenty of room to stand up in, and to move freely between the seats, so as get to and from their places promptly. The question of comfort is in this case left in the background.

Formerly, in England, a space of $1^{ft},48$ between the opposite seats was looked on as sufficient; now-a-days, $1^{ft},93$ is seldom thought enough, and it is often carried to $2^{ft},00$ and farther.

As to the inside height of the bodies, instead of $4^{ft},98$, the figure of the old style of English carriages, the "Metropolitan" has gone to $5^{ft},96$ above the seats and $6^{ft},71$ in the middle of the compartment. A very tall man can thus stand up easily therein.

25. *Construction of the bodies.* — *Figs.* 11 to 14, Pl. IV, showing the skeleton of a second class body on the "Western" of France, are sufficient to give an idea of their mode of construction. The feet of the uprights are fixed into a frame O, O, (*fig.* 13) $0^{ft},46 \times 0^{ft},33$ the longitudinals of which are connected by cross-pieces t, t, $0^{ft},26 \times 0^{ft},25$ and $2^{ft},62$ to $2^{ft},95$ apart, from edge to edge. The principal joints are strengthened by straps and bolts. The cross-pieces support the flooring formed of planks $0^{ft},082$ in thickness, tongued and grooved together, and flush with the top of the frame. The construction of the bodies with an inside passage is simpler, from the suppression of the large door openings. It is unnecessary to insist on this point : a glance over *fig.* 11, Pl. IV and *fig.* 7, Pl. VIII will suffice.

The panels are generally in sheet-iron, sometimes in wood, or in *papier mâché*. Teak, almost given up in France, unless on the "Midi" lines, is often preferred in England. *Papier mâché* which costs the same as teak, has been frequently found to answer well on the "Orléans" lines; teak is reserved for the framework of the body on account of its great resistance to decay.

The roofs of the carriages are in $0^{ft},049$ planks, tongued and grooved, fixed on the curved purlins of the roof c, c, c.... (*figs.* 13) and ordinarily covered with No 14 zinc, that is, the usual number for roofs. Sanded canvas, applied, for example to the "Bourbonnais" carriages, is much less used; it is generally confined to goods-waggons. The gutters, which are of brass, are let in at least $0^{ft},33$ under the zinc and are fixed along the edge opposite to the cornice.

26. *Access to the bodies.* — A word on two rather important details: the fastening of the doors, and the foot-boards.

a. Doors. The doors have usually two (*) fastenings: a turning latch with a handle, and a catch.

The double fastening is certainly a good precaution. The officials see at a glance if the catches are right, and thus accidents are prevented, which, without, would frequently happen to children, as well as the smashing of doors coming open during the passage of the train, and meeting with obstacles. But it is a pity, in certain cases, to have put down the catches so low, that the passengers have great difficulty in reaching them. The intention was, to prevent the consequence of passengers leaving the train before it had properly stopped; but things must not be done by halves, and as it has been settled that passengers are not to be locked in, and rightly (13), nothing like disguised imprisonment should be adopted. The circular of the 11th May 1855, has wisely settled the position of the catches at $1^{ft},64$ at the most below the window openings.

Moreover: the catch ought to disappear from all rolling-stock specially devoted to suburban traffic. The question is, in fact, how to get great crowds along; the passengers must be able to open the doors, with the utmost facility, either in getting out or in. If the porters and others had to put on the catches at each station before the train started, there would be a great loss of time.

b. Foot-boards. The freedom granted to passengers, of opening the doors and leaving their compartments, only to be made use of on their own responsibility and in extreme cases, is, besides, the necessary consequence of the application of continuous foot-boards as well as handrails to passenger-carriages: an application justly recommended to the French companies. There are instances of passengers going by that means, at their risk and peril, to warn the guards of the breaking out of fire, or the giving way of an axle.

But it is particularly for the guards that this side access is intended. When the problem is solved of the establishment of a system of signals, between passengers and guards, the first thing for the guard to do, will be to answer the call of the passengers, and to see into the cause thereof. It is often supposed that the railway companies are on the contrary much

(*) On the Continent of course. *Translator's note.*

interested therein. They are well aware, for example, that a side access which allows an inspection of the train while running, is the real guarantee against criminal disorders. From the point of view of security, the possibility of a guard looking in at any moment, is a valuable check on culpable attempts. If the "Railway Department" has confined itself to recommending continuous foot-boards and handrails, without prescribing the use of them; if the companies although they would find it to their advantage, have not taken upon themselves to urge on their officials the regular use of this means of communication, it is because unfortunately, the clear space allowed by the works, does not admit of it on many lines. The use of the communication along the sides of the train could not be prescribed and regulated. It is for the passengers, a last resource, to which they must not have recourse excepting in face of imminent danger and for the guards themselves, a means they should only adopt when they are certain not to meet with any obstacle, which would be fatal.

There are but few arrangements however good in themselves, which have not their weak points. The communication by means of the foot-boards is in this case: it allows the brakesmen to leave their posts between the stations, get into the compartments, and get back to their places, without being found out. But this disadvantage is not such as to counterbalance the advantages of the communication.

In the origin, the passenger stations had platforms about $3^{ft},28$ high; so that passengers stepped at once into the carriage and *vice versâ;* but this was very inconvenient for the station staff, and for the inspectors of the carriages. It was not the less so for those passengers, at the end of an extra long train, who had to get down beyond the platform.

Low platforms, and the carriages provided with foot-boards correspondingly arranged, have thus prevailed. But this solution is very far from irreproachable. The two boards give a step of at least 1^{ft} in height, all the more difficult to get up and down, particularly the latter, as the boards project to a great extent the one over the other (Pl. II, *figs.* 3, 4 and 8). The outside width of the carriages reaches $9^{ft},19$ (first-class carriages on the Eastern of France). This figure is necessary to allow four passengers to be comfortably installed on each seat. The distance between the outside edge of the upper boards, is $10^{ft},16$ which is scarcely sufficient, in spite of the slight bulging out of the carriages towards the upper part. The distance between the edges of the lower boards must be notably greater, so that the upper board may not project greatly over the lower; but if the first width is limited one way the second is limited the other way, if not so stringently, at least

by important considerations. It is desirable that the passenger-carriages should be able, at a push, to run alongside the platforms of the slow goods, the lines of which may be used for passenger-trains to lie bye in. Now these platforms, as high as the old passenger-ones, have to be as near the waggons as possible for convenience in loading and unloading, so that the foot-boards of passenger-carriages could not be widened without inconvenience.

The lines alongside of the platforms, covered and uncovered, intended for goods, have been sometimes laid down (on the lines of the old *Ardennes* company, for example) without any other idea than that of giving the utmost facility in loading and unloading. Passenger-carriages are of course formally prohibited from running alongside these platforms; and the damage caused to the stock by the violation of this regulation, is punished by severe fines. But this, in some stations, really interferes much with the work, and it is preferable to try to compromise matters, by, on the one hand, setting the platforms back a little, and on the other hand, reducing the projection of the foot-boards a little. In France their maximum distance is $10^{ft},17$ (Pl. II, *figs.* 3 and 4), which reduces to $0^{ft},39$ the horizontal projection of the lower foot-board beyond the upper board. In Germany, the *Vereinbarungen* fix, for this maximum distance 10^{ft} (Art. 178).

On some German lines, the breadth of the lower board has been increased, by means of a movable piece, hinged, which folds over the fixed portion when the carriage has to run alongside a platform wider than usual. But complications of this sort are very irksome to make use of, and little to be relied on.

In result, the side access, such as it is in France, cramped as it is, between the works of the line, on the one side, and the bodies of the carriages, on the other, is very defective. Thus it supplies one of the favourite objections, made by the advocates of the longitudinal communication, with end access. In England the side access, however, is more convenient on several lines, on account of the narrowness of the carriages, which have only three places a side in the first class.

27. *Weight.* — In England as in France the weight of the carriages has gone on increasing rapidly. A first class carriage with three compartments each with eight seats, weighed little more, some years since, than five tons. Going farther back, the weights were less still; the old first class carriages of the "Orleans" line, only weighed $3^{tns},35$ for the same number of places. Now-a-days this weight exceeds 6 tons. On the *Paris*

and Méditerranée system, the weights are comprised between the following limits :

1. *Four-wheeled carriages.*

	Tons Tons	Load		Cwt.	Tons	Dead weight per place Cwts. Cwts.
1^{st} class............	5,25 to 6,05	Load :	24 Pass^{rs} at	1.50	1,80	4,38 to 5,04
» with break.	» 6,09	»	24 »	»	1,80	5,08
Composites.........	4,96 » 5,55	»	28 to 37	»	2,10 to 2,77	3,54 to 3,00
» with break.	7,65 » 7,87	»	32	»	2,40	4,80 » 4,92
2^{nd} class...........	5,00 » 7,40	»	30 to 40	»	2,25 to 3,00	3,34 » 3,70
» with break......	5,90 » 7,24	»	30 to 40	»	2,25 to 3,00	3,94 » 3,62
3^{rd} class...........	5,30 » 7,55	»	40 to 50	»	3,00 to 3,75	2,66 » 3,02
» with break.....	5,30 » 7,58	»	40 to 50	»	3,00 to 3,75	2,66 » 3,03

2. *Six-wheeled carriages.*

1^{st} class............	7,50 » 8,88	»	28 »	»	2,10	5,40 » 6,28
Composites.........	7,05 » 7,72	»	32 to 38	»	2,40 » 2,85	4,40 » 4,06
» with break.	7,80	»	38 »	»	2,85	4,88
2^{nd} class...........	7,05	»	40 »	»	3,00	3,53
» with break.	7,75	»	40 »	»	3,00	3,88
3^{rd} class...........	6,60 » 7,30	»	50 »	»	3,75	2,64 » 2,92
» with break.	7,80	»	50 »	»	3,75	3,12

The eight-wheeled carriages, cited just now (23), of the *Metropolitan* are relatively very heavy. They contain: first class, 48 places; composites, 60 places, 20 first class and 40 second; second and third class, each 80 places. The dead weight is therefore per place : for the first class $7^{cwt},00$; for the composites, $5^{cwt},32$; for the 2^{nd} and 3^{rd},4^{cwt}.

Mr John Fowler has recently had constructed for the "New South Wales" lines, first and second class carriages which differ but little from the preceding ones, excepting in the arrangement of the bodies, and in having a still greater dead weight. The first class carriage 36^{ft} long, contains a central saloon with twenty places, and two end compartments with six each; the second class contains fifty places: the one weighs 15^{tons},5, and the other 15 tons. The dead weight per place is raised, therefore, to 9^{cwt},40 and 6^{cwt},20.

The increase in the weight of carriages is not only the consequence of the more considerable space afforded to each place : it results also from the stouter constitution of the whole vehicle. For passenger-stock, lightness should not be aimed at, and that in the interest of safety. If the vehicle is well constructed, if the material is judiciously disposed, the solidity increases much more rapidly than the weight. The passengers are much better protected against the consequences of an accident, such as a collision, running

off the line, in a heavy carriage, and therefore solid and stable, than in a light and weak vehicle. The work which has to be absorbed in shocks, by the yielding of the elastic apparatus, and at need, by breakage, is proportional to the mass, but the resistance of a well constructed vehicle increases much more rapidly than that.

§ III. **Carriages with special arrangements.**

28. If the compartment with eight places for the first class, ten for the second and third classes, remains the usual type in Europe, it is not the less sought to modify the arrangement so as to carry out certain conditions, either for the comfort of passengers going long journeys, or of the economical working of short trains such as suburban ones.

1st. *Arrangements for long journeys.* — On the great lines of France, the *Western* excepted, a more or less considerable portion of the available first-class carriages contain two compartments and one *coupé*. On the principal line of the *Paris and Méditerranée*, all these carriages, longer than those of the other lines, and on six wheels have three compartments with eight places, and one *coupé*. On the *Northern* of France, some carriages only, a little longer than the others, have two compartments with eight places each, and two *coupés*.

Ordinary *coupés*, deprived of the advantage which made them particularly sought after in diligences, as the look out is blocked, are not very commodious. Their arrangement has no particular feature, and they answer little more than the want of being alone so general among first-class passengers. Their position at the end of the body renders the motion in them more disagreeable than in the middle compartments, where the oscillations are not so full.

Contrary to these, vast compartments, sometimes occupying the whole body, have been introduced on to some lines in England, France and Germany. They are kept for families, or for parties where all the members wish to keep together. Sometimes also, they are placed at the disposition of the public, who are permitted to take their places therein with ordinary first class tickets; although the space in the carriages is much less utilised than in those divided into small compartments. These saloon carriages have generally seats fixed all round the sides, excepting of course in front of the doors; but it is now often preferred to place therein, as in the royal saloons of the "Alta Italia." (Pl. V, *fig.* 10) movable arm-chairs, which

allow the passengers to arrange themselves as they think proper. This arrangement, very good in the day time, is less convenient at night.

Figs. 12 and 13 of plate V represent a saloon of this kind, for the broad gauge, on the "Great Western." Nearly one half of the body is taken up by: 1st a cross passage C; running from door to door; 2nd a W. C; 3rd a dressing closet T; and 4th a compartment for the servants and luggage. Carriages analogous to these, but narrower, run on lines of the ordinary gauge to which the whole system of Great Western lines is gradually being brought. The *Queensland* carriage (Pl. V, *figs.* 4 to 9) is equally laid out in saloons, but without any of the accessories.

29. *Water-closets and dressing-closets.* — For a long time back, much attention has been devoted to giving not only to a few privileged persons, as in the saloon-carriage of the "Great Western," but to all the passengers of a train, at least a portion of the accessories which they find naturally on board of steamers, and in the American trains. The establishment of a W. C. in the luggage-van was the first attempt of the sort. Long ago introduced into Germany, then into Spain, on the line from *Tudela to Bilbao*, this addition was tried in France but with little success. The passenger who has gone into the closet at one station, is obliged to remain there until the next station, and this is so little encouraging that there are few examples in France of travellers falling back on the accommodation. Women would have a still greater difficulty in the matter. It must however be added that the accommodation was never brought to the knowledge of the public; so perhaps otherwise more use would have been made thereof.

In Germany, the conditions have been greatly improved, first in allowing the passengers to install themselves, from one station to another in a compartment C of the brake van, to which, the water-closet W is annexed (Pl. XIII, *figs.* 1 and 2, Austrian State railways); and since, by the construction of special carriages containing two water-closets, one for first class, the other for second class passengers. Each of these is attached to a waiting compartment in which may station themselves, either the passengers of the special carriage itself, or, and then only of course at the stations, those of the other carriages of the train.

The Wurtemberg and *Berg-et-la-Marche* lines have run some carriages of the *Reifert* system (Pl. V, figs. 1 and 2) with a passage, and access at the end, containing four first class places, twenty-four second class, and a compartment W with water-closets, dressing arrangements and so on.

The end platforms π, π, independent of the body, are sheltered by a screen brought over, very light, and which would give way in the case of a shock, without endangering the frame work of the body.

In the express trains of the Prussia and Hanover line, the composite (Pl. V, *fig.* 11) has, on one side, two second class compartments, one with seven, the other with four places, alongside of two closets W, W, one for men, the other for women. At the other end, is a first class compartment with six places : the intermediate space being taken up by a post-office.

These arrangements are convenient of course, but, like those already quoted, they always end in the sacrifice of places; a very important consideration for express trains, the only ones, however, which really have a use for a W. C on account of the fewness and shortness of the stoppages, and of the length of journey made by the most part of the passengers.

30. *Beds.* — For several years, particularly in France, attention has been given to the transport of infirm and sick people. This has been provided by means of an apparatus established in the *coupés*, under the cushion in fact, made at need into a bed. The bed-*coupés* of the *Méditerranée* are charged at the rate of four ordinary coupé places. The passenger has the right to take with him, without further charge, one or two persons who find an accommodation on a supplementary seat, rigged up between the main seat and the end of the compartment.

But the development of the European system, the suppression of breaks in the lines, the always increasing distances that can be travelled right through, have induced some companies to take up the matter in a more general manner. For the persons who, from necessity or choice, take long journeys, a slight increase of the actual travelling rate is a secondary consideration, and they do not mind thus purchasing a diminution of fatigue, which is at the same time a personal gain and an economy of time. In England, where the journeys are comparatively short and where above every thing they want to go fast, the question has little interest; but it is quite another thing on the Continent.

The sleeping carriages of the *Eastern* of France, are simply carriages with three ordinary compartments, with the arms on hinges, already quoted (23). Moreover, the seats can be drawn forward about 0^{ft},33 each, and so form two beds of a sufficient width. One of the ends of the cane-bottom which supports the cushion is hinged, and can be brought up to the required slope. A pillow completes the arrangement, which

is very convenient. But a compartment of eight places, can thus only take two travellers to sleep. Economically, the solution is far from satisfactory.

The price of the compartment so arranged, is that of five first-class tickets, and five persons can of course take their places in it : the condition comes to, then, ensuring to five passengers a complete compartment of eight places to themselves, and permitting them to make use of one of the seats as a bed, for one of them, the four others taking the second seat.

The *Méditerranée* company has carriages with three compartments and a *coupé*, arranged in the same way, and containing thus seven beds, for twenty-eight places.

The company of the *Lower Silesia* and the " Mark " line runs in their expresses, between Berlin and Breslau, composite carriages of first and second class. The first-class compartment, like that of the *Eastern* of France, takes two passengers comfortably for sleeping. The second-class compartment, much more spacious, is a saloon with sixteen places. A third compartment communicating with the other two, contains a water-closet and a dressing-closet.

The composite carriages, constructed for the line from *Berlin to Stralsund*, by the *Railway rolling-stock* Company of Berlin, have a first class compartment with six places, in which the seats can be drawn forward much more; they almost join, and so form beds longways. The number of these beds is therefore half that of the places; but the cross passage thus being done away with, the passengers who occupy the intermediate beds can only leave and get back to their places, by climbing over, as they best can, their neighbour's legs. The length of the compartments so arranged, would be besides often insufficient for tall people.

Instead of drawing forward the seats so as to form longitudinal sleeping-places, the space between the seats can be made use of by means of an intermediate support. Thus in *Reifert's* carriage cited just now (29) and which we shall take up again farther on (73) the second-class compartment with eight places, and reserved for ladies, is furnished with frames that double up under the seat, and are brought out for the night, so as to fill up the space between the seats and thus form four beds.

The *Pauwell's* composite (Pl. VI, *figs.* 5 and 6) of the *St-Petersburg to Warsaw* line, contains four beds; two in one compartment, and two quite separate; but the indifference already pointed out, as to the space so lost, naturally occurs again, and in a more striking manner, in the luxuries of arrangement.

31. *Coupés with folding-beds of the Eastern of France.* — *Coupés* when they are made as long as a first-class compartment, present a somewhat less objectionable solution. The arrangement adopted by the *Eastern* of France, was justly taken notice of at the Exhibition of 1867 (Pl. I, *figs.* 1 to 6). Its principle is borrowed from a piece of furniture, arising from the smallness of Parisian abodes, the cupboard bedstead. During the day, the bed L is put up vertically, the pillow O (*fig.* 5) below, and its underside forms the back of the seat. Pulling out the handle, the whole thing turns over round the axis I; at the same time, the seat S, resting on jointed legs, is pushed forward, and lowered by the rod $\alpha\gamma$ guided by the groove $\alpha\delta$, and thus passes under the bed.

There are thus three places at night as well as in the day-time. Each of the three passengers can not only do what he likes with his seat, bed or otherwise, independently of the two others, but can pass to and from it without disturbing his neighbours, the bed when down, leaving space enough to pass. In this case, three passengers occupy the space of eight; which of course fairly entitles a special rate.

32. *Beds one over the other.* — The most economical solution of the problem, is founded on the berth system of the steamboats, or beds forming two or three rows, one above the other. But the circumstances are more difficult in carriages, where the same space has two purposes : the night arrangement ought to be temporary, easy to set up and take down, and not in the way.

Figs. 1 to 3, Pl. VII, represent a carriage of the *Staats-Bahn* of Austria, including two longitudinal compartments arranged in this way, but the berths are fixed, and of course the compartments only suit for night-travelling.

Although there is only one class in general, in the United States carriages, there as elsewhere, and still more, the companies are inclined to offer these comforts to those who can and are willing to pay for the same. Upon a great number of lines, "day cars" are transformed, for the night into "sleeping-cars". In the ordinary model of sleeping-cars, the seats S, S, across during the day, are lowered and placed lengthways along the sides. Two other rows on hinges *e*, *e'*, up during the day, are let down and kept horizontal by iron rods : on these are placed mattresses (Pl. VIII, fig. 1).

33. *Palace cars of the United States.* — Saloon-carriages, whether for day or night, are increasing every day, on the other side of the Atlantic, and a

celebrated contractor, Mr Pulmann, has created on this desire for luxury, a new branch of industry. He constructs in vast workshops, sumptuous carriages (*palace cars*), offering travellers saloons, dressing-closets, and beds, which he runs on the railway lines, under an agreement with the companies, by which he makes a charge on each passenger of about 16 shillings for twenty-four hours.

In Mr Pullman's palace-cars, the day-seats, joined two and two for the night arrangements, form the supports of the lower beds, the cushions of which are disposed under the seats during the day. Above, at $5^{ft},44$ from the floor, sloping side panels, hinged below, kept up by cords passing over pullies, are let down horizontally, and take the upper beds. Spring mattresses furnished with clean sheets, and curtains which close in the sleepers, complete a bed which may stand comparison with those to be found in hotels. Before night-fall, the change is rapidly made, to disappear in the morning: special attendants having charge of the operation. All this is kept in excellent order, and leaves nothing to desire, but a better access to the upper beds. There is moreover, a separate place for the attendants, a W. C., washing-stands, a supply of iced-water, and a stove with hot water pipes.

The luxury and cleanliness of *Pullman's* cars, are far, it must be said, from being found in the ordinary sleeping-cars, which are often badly kept and very dirty.

34. *Refreshment carriages.* — The line from *Chicago to Burlington* and *Quincy* has been recently constructed, again by Mr Pullman, vast refreshment-carriages (*hotel-cars*), which run between *New-York and Chigago.* These carriages, 59^{ft} long, have a kitchen $8^{ft},86$ long, in the middle, placed between two eating compartments, the one for first class repasts and the other for more humble consumers. This line presents an example of the separation of the passengers into two classes. It has begun to be appreciated in the United States, that real equality is equality in the eyes of the law, and that those whose work has enriched them, are at liberty to profit by their advantages on railways as well as elsewhere : the love of equality is not exactly, moreover, the main feature of the character of the Americans, who are very much given, as we know, to adorn themselves with titles which without anything of nobility in them, are hardly not more serious.

The refreshment carriage is placed in the middle of the train: the first class being on one side, and the second class on the other, so that the use in common of the refreshment-car, does not involve the mingling of the classes.

The tables are movable, and are let down and fastened to the side of the carriage : each of them serves the four places of two seats placed face to face; in the panel which separates the windows is a cupboard containing a dinner-service and table-linen. Under the kitchen is a reservoir kept abundantly stocked with ice, and which allows that commodity to be supplied to the customers in the most varied ways, thus satisfying a taste wide-spread in the United States.

The eating-saloons can be transformed, for the night, into sleeping-places, either entirely or partially. Two small compartments are reserved for those passengers who, while enjoying what they find *on board*, seek to be alone.

In some of these luxurious carriages, a mechanical organ placed in the main-saloon, shortens, for those who like that instrument, the tedious hours of the journey.

Mr Pullman has not the whole monopoly of these splendid travelling habitations. The company of the *Michigan Southern and Northern* line, has had two of them built in its workshops at *Adrian*. They run between Chicago and Cleveland.

35. The weight, per place, of the ordinary American stock is very considerable, as much on account of the space taken up by the passage, as by the great stiffness which the frame must have. The frame is a long beam supported only towards the ends, and has to be strengthened on that account (Pl. I, *figs.* 9 and 10, and Pl. VIII, *fig.* 8). The inconvenience arising from this exaggeration of the weight is necessarily more marked in their special kinds of carriages. One of these, for example, the "Viceroy", by Mr Pullman, weighs 34 tons, and can only take 56 passengers; generally only half that number is reckoned on : the passengers, it is true, often pay double fares for their luxurious accommodation. This dead-weight amounts in fact to nearly one ton per passenger.

Many of the day-cars weigh 24 tons with 64 places, and even 27 tons on the *Erie* railway. Many companies accept with a bad grace these excessive weights, but they must yield to the public wants.

As to the price of these splendid vehicles, that is, of course, also very high. The "Viceroy" quoted just now, cost £ 3,000, without the furniture. This has been surpassed on the *Michigan* line, where the two *palace-cars* cost £ 5,000 each.

The steady and even running of the *Pullman* carriages is much boasted of. It is explained by the great length, and considerable mass of these

vehicles, by the great number of their points of support, and also, whatever may be said, by the less than moderate speed. Without this circumstance, the influence of the state of the line, and the freedom of oscillation of the trucks could not fail to be felt, in spite of the causes of stability.

The transformation of the *day-cars* into sleeping-cars is equally in use, on the *Grand Trunk of Canada* (Pl. VIII, *figs.* 10 to 12). Two seats, each with two places, face to face, are covered over for the night, by two rows of couches, with two places each.

The extra-charge is very small; each passenger provided with his ordinary ticket, pays it, when he takes possession of his night place. By paying double, or four times the fare, the passenger has the right of occupying, either one of the couches, or the space devoted to the two rows. Two special compartments S, S, form, for the night, two double bed-chambers, or one single one, according to the amount paid. At the end of each body, are the usual dressing-closet and W. C.

36. *Hospital waggons.— Figs.* 8 and 9, Pl. VIII, show an hospital waggon or ambulance, employed in the United States during the secession war, and capable of receiving thirty wounded or sick.

H, H... Beds supported by strong india-rubber straps.
A. Dispensary.
B. Surgery.
C. Guards box.

37. The *Nicolas* railway (St. Petersburg to Moscow) which has adopted the American stock, has carriages (Pl. I, *figs.* 9 to 11) the arrangement of which is analogous to that of the sleeping-cars. The first-class body, carried on two four-wheeled bogies, contains : 1st six compartments with a lateral passage L, L; 2nd an upper compartment or story, occupying the middle portion. Five of these lower compartments are of the same length; the sixth, a little longer, contains the staircase E, E, which leads to the upper story, furnished with beds all complete.

External width	$9^{ft},67$
Insides height	$8^{ft},00$
Height of the upper story	$6^{ft},38$
Total height above the rail	$16^{ft},93$

Each compartment has six places, but after the beds are put up, there are only four.

The beds are placed cross-ways, the seat *s* lifts up vertically, turning on a hinge *e*, *e*, *e*; and rests against the side of the carriage, the back itself turning down horizontally round a hinge *e'*, *e'*, and forming the bed. There are thus, two beds A, A, at a good height above the floor, to allow of two more being laid down under them, on the floor. There is a water-closet at each end, W.

During the day, ottomans and curtains applied to double windows ensure the passenger's complete comfort.

In the second class, if the ottomans are not enough, the passengers arrange themselves as they best can, during the night, on frames, which take the place of the network shelves for small packages.

38. The double arrangements for day and night, are equally adopted in India. The workshops of the *Metropolitan Carriage Building Company* at Saltley near Birmingham, have sent out to the *Great Indian Peninsular*, carriages of this kind; the body 24^{ft} long and 9^{ft} broad, is divided into two compartments, each of which carries six passengers. For the night, hinged backs stuffed with spring cushions, are lifted up and fastened horizontally, and double the surface of the cushions, in such a way that the twelve passengers can lie down on the two rows so formed. Each compartment has its side-doors, a W. C. and a washing-stand; by closing the door between them, one can be kept for gentlemen, the other for ladies.

With these summary details of trials which ought to be followed up, in order to arrive at a combination of comfort and economy, we shall content ourselves.

We shall now pass to carriages specially designed for short distances.

39. *Carriages for short journeys.* — If, in certain respects, that is to say in regard to facility of getting in and out, carriages for short journeys are sometimes more exacting than the others (23); it is evident that comfort is less essential in them, that certain arrangements inadmissible for long journeys, are quite satisfactory for short runs, and may even be preferred when the weather is favourable: hence the use of carriages with an "Imperiale" (*) greatly in use on the suburban lines. Economical, on account of the relatively considerable useful load, they are also of great use,

(*) The author is of course speaking of France; the "imperiale" consisting of seats like those on the top of the tramway cars, but cross-ways, and covered with a roof. *Translator's note.*

on days of great traffic. They allow of 1600 to 1700 passengers being despatched in one lot, thus meeting every requirement with the regulation maximum of 24 carriages, and so preventing the necessity of the trains following too closely.

Up to the present time, the "imperiale" places are simple wooden benches, protected only by an awning. The air and the view make them run after in summer, but they are avoided in winter. Their access which is often difficult, renders them only available for those who are active and not nervous.

The question of access is one of importance. The side steps like those of the teak carriages on the *Western* of France are inconvenient and even dangerous to get down from. It is almost impossible to establish a convenient side access; such suits ill with side-doors, and a passenger from inside is apt to receive on his head, the foot of a passenger hurrying down from the "imperiale," and who is feeling with his feet for the steps.

The access at the end, applied later on to the carriages of the *Western* of France and of the *Vincennes* line, is a real improvement. The straight staircase *m, m, m,* (Pl. IV, *figs.* 1 to 5) of the "Ouest," is more convenient than the turning one of the *Vincennes* line, but the latter has the advantage of bringing the passenger up at the very end of the direction he has to follow, to take his place; while the two staircases of the *Western* of France leading to a joint landing ϖ, ϖ, on the centre line, necessitates a change of direction, which involves no danger, but causes a delay in getting to the seats. In seeking for an available place, or one to suit his convenience, the passenger passes along that way; steading himself by a handrail *t, t, t,* fixed on the imperial at a suitable height, held up by curved supports, which leave the rail continuous.

Some falls have caused this arrangements to be blamed as full of danger. The smallness of the side-pieces which run along the outside of each side access, has been particularly found fault with. These may indeed, aggravate the consequences of a fall, because by retaining the foot of a passenger imprudent enough to omit taking hold of the rail, they give him a twist which sends him over on his head. Some accidents of this kind have taken place on the *Vincennes* line. These pieces could be brought to elbow height, but this remedy would be worse than the evil : the passenger would then lean over, and would be struck by the bridges and so on : the wisest thing would be perhaps to do away with the pieces altogether.

The best proof, however, that these carriages offer no serious danger, is the extreme rarity of such accidents, which are infinitely few, with relation

to the immense movement of traffic on the lines in question, and which besides occur only, for the most part to people in a state of over-excitement, of whom there are always plenty of course in suburban trains, particularly in coming back on Sundays and holidays. But if the "imperiales" of the *Western* and of the *Eastern* of France are not really dangerous, they are but of mediocre utility: they are not suitable for women, or for old or infirm people. In winter no one wants these places, which are then of course non-paying. There would therefore be a notable advantage for the companies, to render these places as safe and convenient, at least as those of the second class.

40. *Carriages with two stories closed.* — The study of this arrangement proposed as far back as 1855 by M. *Love*, carried out later on by MM. *Molinos* and *Pronnier*, who, in 1862, constructed for the line from *Lyons to la Croix Rousse*, carriages with a closed "imperiale," has been taken up again by M. *Vidard*, whose two-storied carriages have obtained deserved success (Pl. VII, *figs.* 4 to 10).

A central passage C, C, (*figs.* 6 and 7) replaces the two side ways: this gives an upper compartment similar to an American carriage. Seats with cushions, panels with mirrors, doors shutting the passage, staircases *m*, *m*, of easy access, render these places as convenient in all weathers as those of the lower story and accessible to every body.

At first sight, nothing would seem simpler than this modification; but there was a difficulty. Being placed under the roof, the passage requires this latter to be widened, and the cornice projects beyond the regulated dimensions. To bring them within, the whole body has to be lowered, which involves serious modifications in the construction of the carriage, more especially with regard to the longitudinal bearers, which have to be turned up at each end in the shape of a swan's neck (Pl. VIII, *figs.* 4 and 5, and Pl. X, *fig.* 6) to bring up the buffers to the normal height of $3^{ft},28$; the drawing and buffing springs have therefore to be moved, and are brought towards the ends R, R, (Pl. VII, *figs.* 4 and 5).

M. *Vidard* has substituted for the simple longitudinals in T iron first employed, double longitudinals in U iron, forming a very stiff open girder (Pl. X, *fig.* 6). The swan-neck is formed of an iron plate fastened between two U irons placed back to back and solidly fastened together.

A first specimen, constructed by M. *Vidard*, and bought in 1864 by the *Eastern* of France was put on the line to *Coulommiers*. This carriage contains: 1st two first-class compartments, with four places, and capable

of being turned into a bed-coupé, which at any rate, is of small importance for a stock intended more particularly for short journeys; 2nd two second-class compartments with ten places; 3rd thirty-two third-class places (the whole upper story).

The maximum width between the edges of the foot-boards is $10^{ft},11$. The width of the body at the cornice, and at the waist being nearly as great, these foot-boards are not very convenient.

The success of this trial determined the company *Eastern* of France to construct carriages on the same system, but slightly modifying the arrangements:

Lower body	First class	8 places	38
	Second class	20 »	
	Third class	10 »	
Upper body	Third class	40 »	
	Total	78 places.	

These composite carriages, weighing 7 tns, 6, and costing £490, are attached to the service of the *Haut-Rhin* and *Bas-Rhin* branches, and of the Grand Duchy of Luxemburg lines, worked by the company of the *Eastern* of France.

A few carriages, third class only, containing forty places on each story, have been recently constructed: they weigh $7^{tons},40$, and cost £ 202; they run on the lines from *Paris to Meaux* and *to Coulommiers*. They have given great satisfaction; and it is to be regretted that they cannot be applied to the line where the suburban traffic is the heaviest, that is to say on the *Vincennes* line; but in spite of its comparatively recent construction, this line has a more restricted clear space to pass through, than the others.

M. *Vidard* lays down in the following terms, the economical advantage of his system (*):

" From the economical point of view, the following result gives the amount of saving.

" Our locomotives with four wheels coupled, weigh from 25 to 28 tons; they possess a tractive power of from 3 to 3,50 tons; they draw, at a regulation speed of 28 miles an hour, and with an expenditure of fuel of from $26^{lbs},4$ to $28^{lbs},7$ per mile, trains of sixteen carriages of a total weight of 130 tons.

" These trains of 130 tons contain 640 available places, of which three quarters at most are occupied, by 480 passengers. The receipts, at a mean rate of $1^{d},2$ per passenger per mile, are, for each train, 48 shil. per mile. The dead-weight drawn is 96 tons.

" With the carriages of two stories, a train of 130 tons drawn by the same engine,

(*) Minutes of proceedings of the " Société des ingénieurs civils, of Paris." — 4th May 1869.

under the same conditions of speed and with the same expenditure, would be composed of twelve carriages with 70 places each, and would contain 840 available places, the three quarters of which being occupied, would take 630 passengers.

" The receipts per train mile would be in this case, 65 shillings; and the dead-weight only 84 tons.

" The difference per train mile in the receipts of the two trains would be 15 shillings in favour of the train with two-storied carriages; and a reduction in dead-weight of 12 tons. "

This is correct.

The two-storied carriage is suitable besides for short journeys, equally well for a light traffic, as for those enormous rushes of traffic, which occur on certain days, in the neighbourhood of great capitals. Upon branches, upon subsidiary lines, a single carriage will often do, and in the case of steep gradients, the economy arising from the smallness of the dead-weight, will be considerable. It must sometimes inevitably happen, that a carriage has to be put on to a train for a small number of passengers, but on account of its comparative lightness, the disadvantage of this, is less felt than with the carriages of great capacity, cited farther back (22). As to the service of the great lines, the two-storied carriage seems scarcely adopted, even for ordinary trains, as these sometimes run as fast as expresses. M. *Vidard* remarks, " that he has obtained, by a considerable lowering of the frames and the passengers, seats in the two bodies, a centre of gravity lower, with reference to the ordinary carriages with " imperiales" by $0^{ft},39$ to $0^{ft},49$, empty, and by $0^{ft},65$ when loaded, whence he concludes, that with these carriages, speeds of 37, 43, and 46 miles, which are those of express trains, can be attained with perfect safety". But these speeds are often gone beyond. It is not besides to the ordinary carriage with " imperiale", but to the carriage *without*, that the new pattern must be compared. Now, admitting that steady running may be relied on when there is a full load, that would not be sufficient, and it is not probable that it would be the same, if the lower body were empty, or nearly so, and the upper body on the contrary very full, which could not fail to be often the case, if the upper body were devoted to the cheapest places.

In suburban service, where all the trains are first, second and third, and the stations very close together, the speed is always low, and this division of the load would be attended with no disadvantage : but it would be quite another thing with express trains.

41. The little branch from *Enghien to Montmorency* with its gradient of

one in 22, is greatly interested in a reduction of dead-weight. The stock contains however, at present, only one special carriage. The others are the carriages of the "Nord", which works the line. The special carriage constructed by MM. *Leprovost* and *Guéroult*, belongs to the double story type.

The lower body contains {	two first class compartments.............	20 places
	two second class id.	24 »
And the upper body,	third class................................	40 »
	Total....................	84 places.

It weighs $8^{tons},67$.

The great width and lowness of the body are inconvenient for getting to the axle-boxes.

Carriages with two stories on the lines of *les Charentes*, from *Fougères to Vitré*, of Médoc, from *Perpignan to Prades*, on the "Ceinture" round Paris, etc.

42. *Action of the wind.* — Carriages with "imperiales" may at first sight give rise to fears, on account of the great surface exposed to the action of a side-wind. But it is easy to prove that the velocity of the wind, for which the moment of overturning the carriage would approximate to the moment of stability, is so rarely attained in temperate countries that any provision for this is unnecessary. There have been examples, on the line from *Narbonne to Perpignan*, and that from *Vienna to Trieste* (passage of the *Karst*), of carriages blown over by the wind, to the action of which, however, they offered less hold than those in question. But where should we be, if we were to regulate the establishment of rolling-stock by two or three isolated facts! It would be as necessary to render buildings and above all roofs, capable of resisting whirlwinds, because these, from time to time commit ravages.

43. With regard to economy of dead-weight, the carriage with two stories, would have been nowhere better placed than on the temporary line from *St. Michel to Susa* with its gradients of one in 12. But it was feared, doubtless, to raise the centre of gravity, and to increase the hold of the wind: a wise fear, notwithstanding the hold which the central rail gave to the carriages, when it is a question of a line crossing the Alps at an altitude of 6900 feet. The inside of the carriages was arranged in the simplest manner. The seats were longways, and on account of the narrowness of the bodies, in keeping with a line of $3^{ft},6$ gauge, there were only tow rows, as in an omnibus. The relative dead-weight, however, is considerable.

	Tons.	Nº of places.	Dead-Weight per place. Cwts.
First class..............	5,48	24	4,56
Composite..............	5,28	26	4,06
Second class............	5,36	28	3,82

A proportion as unfavourable as that of the carriages on the great lines (27) running on comparatively flat gradients. It would be of consequence to get rid of so onerous an equality; but that would be difficult, on account of the necessity of a stout constitution, and special stopping appliances, without having recourse to two stories. In the case of the "Mont Cenis" line, besides, a saving in the weight of the carriages would have but a slight effect. On such gradients, the dead-weight that wants reducing, if not entirely suppressing, is that of the moving power.

We shall return, farther on (184) to the arrangement which allowed the carriages in question, to run round curves of 130 feet radius (*).

44. Carriages with two stories were introduced some time since in India. Mr J. Edwards Wilson, engineer-in-chief of the "Oudh and Rohilkund" system of lines, tried them first, in teak, on the *Nulhatee* branch line in Bengal, and afterwards constructed a large number in metal, on the same plan for the *Lucknow and Caunpore* and other lines. Pl. II, *figs.* 9 to 14 have been engraved from his designs.

The length is very considerable, $58^{ft},75$. The lower story is $6^{ft},75$, and the upper one $4^{ft},75$, clear height. The first only is provided with seats; the other, forming the second class, is intended specially for the natives; they squat on the floor, a manner of sitting preferred by Eastern people.

This carriage presents many peculiarities, and among others, the exclusive use for the whole frame-work, of metal, and mostly cast-steel. The body forms two hollow lattice girders, placed one over the other, with the two sides united together 1st by the diagonals B, B, which tie the longitudinals together and by the lower flooring of corrugated steel-plates; 2nd by the roof, also of corrugated steel-plates, forming the floor for the upper story; 3rd by the curved pieces *c*, *c*, *c*, of the upper roof; by the stouts E, E, which go from the lower floor to the upper roof. The lattice bars are of Ω section, one often adopted for bridges. This carriage is carried on six wheels of

(*) This line, which was only temporary, was removed soon after the opening of the Mont Cenis Tunnel, in the end of 1871.

large diameter, $4^{ft},00$, penetrating far up into the body, only $2^{ft},36$ above the rail, and covered over with large boxes T, T, (*fig.* 12); the distance between the end wheels extending to $45^{ft},25$ special arrangements had to be introduced to allow of passing through curves.

These carriages accommodate 200 passengers each, and, weigh 13^{tons}: giving the very small dead-weight per place of $1^{cwt},25$. The teak ones first mentioned, which are run at a very low speed, only twelve or fourteen miles an hour, weigh $7^{tons},5$, and carry 150 passengers; so that the dead-weight per place is still less, only 1^{cwt}, or considerably less than the weight of a passenger.

Colonel Kennedy has also introduced two-storied carriages on the *Bombay and Baroda* line. The carriage, a third class, is 22^{ft} long, only $8^{ft},5$ broad, and 13^{ft} high above the rail. It takes seventy passengers in the lower story, and sixty in the upper. Particular care was taken to make the carriage very light, especially in the roof. Its centre of gravity when loaded, is little higher than that of ordinary carriages.

45. *Standing carriages.* — To this class of special carriages for short journeys, belong *standing* carriages, or fourth class, almost entirely given up everywhere, but which are, notwithstanding, perfectly warranted in certain industrial and agricultural districts. Workmen and labourers, going to their work or to market, care more either going or coming, for a low fare than for seats. They do their distances quicker, and although standing, with much less fatigue than on foot. These fourth-class carriages (*Stehwagen*) are run in Hanover, where they were introduced at the end of 1867. They are of a nature to satisfy the most exalted philanthropy, and in no way remind one of the old open trucks, so much criticised in a manner doubtless more sincere than enlightened; as they were only for short journeys, and at a velocity too small to add to the effects of the weather. To complain of the slow rate at which travellers of small means are conveyed, to demand that they should be comfortably and wholesomely installed, is all right enough, when long journeys and night travelling are in the case. But to denounce bare and consequently economical accommodation, only intended for very short journeys, is to do the working and agricultural population a very bad turn. For these short journeys are of more consequence than long; what concerns them is to do these short journeys quicker and with less fatigue than on foot, and at a greatly reduced fare.

The Hanover carriage can carry sixty passengers with their loads, tools, baskets and so on.

During the war of Prussia with Austria, these carriages were appropriated

to the transport of men severely wounded. Their arrangement was analogous to that of the American ambulance-waggon (36). The berths, twelve in number, were placed on two stories against the sides of the carriage, and hung from hooks by india-rubber rings, to reduce shocks. The two rows leave sufficient space between them for the service of the attendants and surgeons. The doors, on hinges and divided into two unequal flaps, were opened the whole width to let the litters pass: the widest flap alone was opened for ordinary purposes.

These carriages are also made use of for the transport of troops. Forty-two men are accommodated on portable benches placed longways.

46. This is not the place, however, to treat of the application of railway-rolling-stock to military transport. Railways are powerful instruments of peace; their development, so intimately bound up with the progress of enlightenment, ought logically to lead one day, to the extinction of prejudices, national antipathies, and spirit of conquest, and to an enormous reduction, if not to the suppression of our overwhelming permanent armies, which paralyse, and transform into heavy public burthens so many precious elements of production. But this grand reform will be a work of time; and it is to be feared that, more than once again, railways will serve as instruments of war. Looked on from a purely technical and industrial point of view, that of the rapid conveyance of men and things, in large masses, the subject is one of real interest; but the French regulations thereon, dating back to 1855 require revision; they are now being revised, and there would be no use in dwelling on them just now (*).

§ IV. — Internal lighting.

47. *Candles. Lamps.* — Candles are sometimes used in Germany (Pl. IX, *fig.* 42). The glass breaking is no drawback; but this mode of lighting is dear and the light poor. It is well always to have the means of lighting put out of the passengers' reach, which is of course easy with candles as well, placing them, like on the "Thuringen" line, in a glazed opening in the panel, and only got at from the outside.

(*) A new *General Regulation for Military transports by Railways* was decreed by the President of the Republic, on the 1st July 1874. But it does not appear to us, that extracts from that document may be usefully made. *Author's note.*

It is especially on account of the easy solidification of oil in winter, that the candle is preferred in the north of Europe, upon the " Eastern " of Prussia, for example, which has long given up oil; but the addition of a small proportion of petroleum is sufficient to keep oil fluid at the lowest temperatures. Looking after it, and at need a few sharp fines easily prevent its abuse, and consequent dangers.

A regulation of the "Eastern" of France, dated the 23rd January 1868, gives the following recommendations on the subject.

With the object of preventing the lights going out in several posts, instructions have been given that colza oil mixed with 3 per cent of petroleum shall be used for the toil lights, side lamps, and the lamps inside the carriages, as long as the temperature is below freezing point.

Conformably with these instructions, the mixture must be made by the head lamp-man, and the figure of 3 per cent (3 parts of petroleum and 97 of oil), in no case is to be exceeded. Notwithstanding, lamp-men have used pure petroleum, thereby causing flames to be produced which might have had serious consequences. Thus a toil lamp has been spoiled and an inside carriage-lamp, upon the wick of which petroleum had been poured, took fire on the way and might have burnt the carriage.

To prevent the recurrence of such accidents, it is once more repeated that the employment of pure petroleum in train lamps, and toil lights, which burn colza, is formally prohibited, and that severe penalties will be inflicted on those preparing or allowing lamps to be so prepared.

Station masters are instructed to look well after this part of the service, and to use every recommendation so that the mixture of petroleum and colza to be employed during frosts, should under no circumstances be modified.

The head lamp-men are specially instructed to see this mixture carried into effect, and to superintend its use.

An oil-lamp has generally been adopted, enclosed in a sort of lantern with a glass bottom, let in through a circular opening in the roof (Pl. I, *figs.* 1 to 5, 12 and 13).

In the first-class carriages, each compartment has its lamp in the centre, and thus distributing the light without inconveniencing the passengers, who can besides reduce it very much by a small curtain pulled over the bottom of the lamp.

In the second and third classes, the lamp is sometimes placed above the partition, and so does for two compartments.

Ordinary lamps (*figs.* 12 and 13) have one single burner with a flat wick. When they work properly, they give enough light for all the passengers in a first-class compartment to read easily, even those farthest off. But the

light, all right at starting, often becomes very dim after some time, either from the imperfections of the lamp, or on account of the violence of the current of air, which is not always sufficiently checked, notwithstanding the reversed position given to the openings t, t, t, by which the air passes into the lamp.

Lamps with *Argand* burners, or with a double current of air, are in use on several German lines; the *Theiss*, the "Northern" of Austria have tried mineral oils, but with small success.

Among other advantages, the position of the lamps gives a notable one; it allows them to be attended to from the outside and without troubling the passengers. But on the other hand, the lamp-men have to get up on top of the carriages, which requires a certain time, and does not allow the lamps which burn badly to be attended to, excepting at the stations where the trains remain some time. The work of the lamp-men who have to pass from roof to roof in the dark, presents besides a certain danger, which is diminished on some German lines, by fixing on the roof at each end, a plank, projecting as far as the first portions of the buffers, and so reducing the space to be stepped over. To facilitate the getting on the roofs luggage vans are often furnished with a double flight of steps at one end, with handrails, so as to save the lamp-men using ladders.

The lighting of carriages is an important detail and very often neglected. It involves besides only a slight expense. On the system of the "Eastern" of France, one of those where the carriages are the best lighted, the consumption of a lamp of *Mulot's* system is three quarters of an ounce of oil an hour; which at the mean price of colza oil in 1868, 9d, brings out the cost per hour for one compartment, first class, to one tenth of a penny.

48. *Lighting by gas.* — The lighting of railway carriages by gas, scarcely attempted in France and Germany, has been rather extensively applied in England. It is portable gas of course which is employed. It can be stored either, as on the *North-London*, the *Lancashire and Yorkshire* lines, in one general reservoir, placed in a special compartment of the luggage van, and distributing the gas throughout the train, by means of an india-rubber pipe, or as on the metropolitan, in one or more special reservoirs placed on each carriage. The reservoirs, with impermeable sides of india-rubber, are fixed on the roof, nd a metal cover gives by its weight the necessary pressure. They are filled at the principal stations, by means of lateral tubes

adapted to the carriages, and at convenient lengths, attached to the conduit, which runs parallel to the rails.

The first arrangement is suitable for trains which are not liable to be broken up.

The evident objection to portable gas, is the considerable space it takes up, when the supplies can only be renewed at rather long intervals. Some companies submit the gas to as much compression as the flexible sides of the reservoirs will permit of. Thus the *North-London* has set up in its work-shops at Bow, a very simple apparatus with a column of water, which delivers the gas under an effective pressure of $9^{lbs},6$ on the square inch. When the gas is compressed to a high degree, in metal receptacles of constant volume, all objection is removed. The "South-Eastern" has begun to use gas stored under a pressure of from 9 to 10 atmospheres, compensating by means of a regulator, for the loss of pressure due to the consumption. Some trials have also been made in Belgium with gas from Boghead coal, which the carriages of the *Molenbeck-Saint-Jean* company, distribute under a pressure of from 10 to 12 atmospheres. The light is very fine, and far superior to that of the lamps. Compressed gas seems to be the most suitable solution of lighting carriages. But the companies themselves would have to, in almost all cases, undertake the compression; no wonder they hesitate. As far back as 1850, gas lighting under a pressure of 11 atmospheres was tried on the line from *Paris to Strasburg*. The apparatus set up by M. *Hugon*, was composed of two cylindrical receivers of $5^{ft},35$ long, $0^{ft},79$ in diameter, and with the sides 0 in,12 thick. The regulator, a small reservoir containing 0,35 cub. ft., was closed at one end by a flexible membrane which conveyed the pressure to the end of a lever, the other end of which controlled a valve placed at the starting point of the supply-pipe, between the reservoir and the regulator. The whole was fixed in a wooden case, fixed on the frame, towards the centre.

In spite of the success of this trial (the only defective point was vacillation of the flame at high speeds), and although in regular running, the lighting was better and more economical than that of oil-lamps, these have been adhered to so far, as being simpler, and after all, sufficient.

49. It has recently been sought to produce mechanically, a sort of gas, a mixture of air and oil in suspension. The "Eastern" of France has tried to realise this idea, and to apply it to lighting trains; the air compressed by a mechanism which takes its movement from the rotation of a spindle, passed through a reservoir full of naphtha, charging itself thus with oily particles,

and the mixture had to burn in burners of suitable shape. These trials did not succeed in the trains, and have been given up; but the process still works with a certain success for the lighting of some of the stations.

§ V. — Heating.

50. *Foot-warmers containing water.* — The ordinary way of heating by foot-warmers containing water is very primitive: the heat, often excessive on starting, goes down to nothing after an hour or two. The changing of the foot-warmers is, particularly in the night-time, a most disagreeable operation for passengers. Keeping the doors open, the passengers having mostly to be disturbed on account of the changing of the foot-warmers, and the noise caused by that operation, all that constitutes one of those little disagreeables, not very serious after all, but which are put up with, with a bad grace, because they are felt to be *not* inevitable. It is considered, not without reason, that the privilege of being badly warmed, is paid for rather too dearly.

On some lines, it has been thought well to cover over the foot-warmers with thick woollen stuff. This allows the feet to be placed on the warmer when the water is very hot. But far from preventing the warmers from cooling, this covering on the contrary assists them to cool. The bare metal being well polished, radiates far less; all that is required is only to place a non-conducting substance such as a piece of wood between the warmer and the floor, to prevent the cooling from the bottom by conduction.

The apparatus in use on the *Paris and Méditerranée* system, is a vertical boiler with inside fire-grate. From the side (Pl. IX, *figs.* 35 to 41) is taken a horizontal pipe called *rampe*, provided with a certain number of cocks r, r, r, under which the foot-warmers are put to be filled.

It is difficult for the man in charge to look after the filling of several foot-warmers at once, and it is only when he sees the water run out that he knows they are full.

To avoid this inconvenience, small reservoirs have recently been added, R, R, R, containing each two gallons, above the main-pipe, at the point where each branch takes off. These branches are closed by means of a three-way cock with a long handle (figs, 38 to 41). While the water is heating, the handles are parallel to the main-pipe. To fill the foot-warmers, each cock is turned a quarter of a turn, a warmer is placed under each of the small reservoirs, and the handle is brought back to its original position.

The first operation establishes the communication between the boiler and the small reservoir R, which thus fills with water. The second operation shuts off this communication, and at the same time opens the cock to the foot-warmer. Stops are put to prevent the cock being moved more than a quarter turn.

Two gallons are the capacity of the foot-warmers of the latest pattern, 3 feet long, and elliptical in section.

The nozzles of the cocks, ought to be $2^{ft},78$ above where the warmer is laid to be filled; but it is wrong to lay the warmers right on the ground, which is frequently wet, as the men often run the cold water out there. In order always to have a dry place to lay the warmers on, a bench P, P, should be put under the main-pipe, against the wall, from $0^{ft},33$ to $0^{ft},39$ in height.

The time required to bring the water to the boiling-point is generally 45 minutes. It is therefore easy to determine whether there will be time enough to renew the water between two consecutive trains, or whether an apparatus of double capacity must be set up. The capacity of the boiler is 20 gallons for each cock. There are seven calibres of apparatus, having respectively 1, 2, 3, 4, 6, 8, and 10 cocks, and consequently capacities of 20, 40, 60, 80, 120, 160 and 200 gallons. Their prices vary from £ 11 to £ 56.

51. *Heating by sand.* — On a certain number of German lines ("Eastern" of Prussia, "Lower Silesia", and "la Marche", and so on) a similar but much improved method has been in operation for some years. The water is replaced by sand, or better still, coarse gravel, brought to a high temperature, which cools much slower than water. It is sufficient in general, to last about four hours. The substitution is carried out without disturbing the passengers, without freezing them in the first place by opening the doors. The sand heated in a furnace, is run into a little sheet-iron case (Pl. IX, fig. 42) which is introduced under the seats by a special door. The case is isolated from the floor by iron rests *t*, *t*, and a sheet-iron screen prevents the partitions being too much heated. Hot air thus surrounds the passengers' feet, who have no grounds to regret that they have no foot-warmer to place their feet on. This arrangement is preferable to that in use here; but the expense of starting and keeping up the furnaces, in which the gravel is brought almost to a red heat, are much more considerable than with water.

52. *Stoves.* — The division into small compartments certainly complicates the question of heating. Large spaces can be heated by stoves. Such

is the case with the travelling post-office vans. Saloon carriages, some of the third and fourth class carriages in use in Germany, and the bodies of which are not divided into compartments, and *a fortiori* the great American carriages, and in general all stock with passages and longitudinal communication, in which the guards and others can regulate and look after the apparatus, which could be left in the hands of the passengers without danger. These grates have, besides, the drawback of distributing the heat very unequally throughout the space they have to heat. In America, stoves have now and then, and just recently on the *New-York and Erie* line, greatly added to the consequences of collisions, by setting fire to the carriages and their occupants.

Figs. 43 and 44, Pl. IX, represent the stoves which have long been employed for heating saloon carriages on the "Eastern" of Prussia. The fuel is charcoal, very fine. The stove is fed at the upper part from the top of the carriage. The combustion is effected only on a layer of no great thickness, above the grate, the development of heat only takes place at a small distance above the floor, which is a favourable condition.

It is indispensable that the lid at the stop of the shaft should close hermetically; as without that the draught, instead of going entirely through the side-chimney *c*, *c*, *c*, would take, partly, the more distant road : the whole of the fuel would be soon incandescent, and the heat excessive. The lighting is easy; in case of some obstruction putting the fire out, very rare by the way, the guard ought at the next station to open the lid, free the column of fuel by means of an iron rod, and relight the fire.

The management of the stoves should never, on any pretext, be given over to passengers.

In ordinary weather, with the draught suitably regulated, this stove once lighted, remains alight for fifteen hours.

53. *Heating by steam. a. Waste steam.* — Heating by steam would seem, at first sight, to be pretty naturally indicated; there is, in effect, an abundant source of heat in the condensation of the waste steam from the engines. Trials were made in this direction as far back as 1858, upon the "Upper Silesian" line; but were given up without reference to the difficulties in carrying out the proposition, but because it is in winter that the engine requires all its power, and it was feared that a back pressure on the pistons would be created.

Endeavours in the same way have been made in France, but have not been followed up.

It is not that the thing is not possible in itself; nor is it either that any notable increase in the back pressure has been clearly proved.

It is independently of these considerations, that heating by waste steam had to be given up.

The establishment of a sort of serpentine conduit for the circulation of steam under the floor of each body would be costly. The flexible tubes for joining from carriage to carriage would be still more costly, particularly in keeping them up. Moreover all the goods stock would have to be provided with a conducting tube, for any waggon may have to be put into a passenger-train.

Adding: 1st that the breakage of a tube towards the front of a train would leave all the rest to freeze; 2nd that the passenger-carriages often placed at the end, in mixed trains, as much to save their couplings as to relieve the passengers from the knocking about from operations at stations, would receive very little heat in long trains; 3rd the necessity of special couplings with flexible junctions is a very serious drawback in practice. All things duly considered, the idea of thus utilising the heat which the steam wastes in the air, is specious, but will not bear the test of investigation.

It is not, as has been made out, because this method would have the natural result of heating the carriages of all the classes, that it has been rejected by the companies. In the first place, heating the carriages not being compulsory, nothing would prevent the serpentine conduits being applied only to the first class compartments, and only putting the simple conducting tube, to the second and third class carriages. The companies would wish nothing better than to heat all the classes, if that could be done by simple and economical means. If they adhere, legitimately, to keeping up between the different classes, differences in accommodation in ratio with the rates, they know very well that all that tends to do away with, or diminish the serious inconveniences of railway travelling, turns definitively to their advantage, and if, in particular, the heating of the second and third class carriages had the effect of depreciating the first, this effect would be compensated for, and more, by the increase of traffic.

b. Employment of a special boiler. To avoid coming upon the engine for accessory duties, which might interfere in certain circumstances with its main functions, several German lines ("Eastern" of Prussia, *Cologne to Berlin*, "Lower Silesia", Bavaria) have tried to carry out the heating of the train by a small boiler specially established in a compartment of the luggage van. On the "Eastern", tubes one inch in diameter, with junctions in india-rubber distribute steam through small branch tubes which lead into cylin-

ders placed under each of the seats. Sufficient heat was obtained in this way. The cocks regulating the admission of the steam into the cylinders, can only be worked from the outside. Previous arrangements which permitted the passengers themselves to work them, were abandoned on account of some drawbacks they presented.

In Bavaria, the vertical boiler is sufficient for ten or twelve carriages. Inside cocks allow the access of the steam into each of the cylinders to be regulated, and to be cut off altogether. A small blow-off cock at the middle and at the bottom of each india-rubber junction, lets off the condensed steam, which accumulates in the angles.

On the line from *Cologne to Berlin*, the steam circulates in longitudinal tubes placed directly under the flooring, $0^{ft},23$ in diameter. Between the seats, these tubes the number of which varies from 2 to 4, are covered by a sheet of iron; under the seats, they are uncovered, so that, there, the radiation acts freely.

Similar arrangements are frequent in the United States, although the rolling-stock is very suitably heated by stoves.

54. Hot air stoves are also applied in the United States to two saloon carriages on the *Michigan* line (32). Hot air is sent in to the bodies of the carriages, through tubes let into the sides.

§ VI. — **Ventilation.**

55. The windows are the ordinary means of regulating the access of the air into the carriages. Balanced windows, which keep themselves at any degree of opening, are more convenient than those which can only be fixed in a small number of different positions, by the holes in the strap.

The continual vibrations of these window frames, have a good share into the noisy running of the carriages. The best means of checking that noise, is to cover the frames with a velvety material, as is done on the *Orleans* system. Without dwelling too long over this detail, we may notice, in passing, another means, in use on the "Northern" of France, and on the *London, Chatham and Dover*, which seems efficient. Between the springs ordinarily employed to keep the glazed frame against the sides of the opening, and the frame, is placed a tongue of wood, fixed at its lower extremity. This tongue pressing against the frame, for the whole height the window is up, checks

the vibrations much better than the springs, which only press against the frame at one or two points.

This means of ventilation is very imperfect.

Ventilators of sheet-iron, with a broad plate over the top, are of little efficiency. They have only been adopted in France, by the Post-Office, for its travelling vans.

Fig. 3, Pl. IX, represents a little apparatus of Mr *G. Creamer*, much used in the United States. A flap A, A, is movable round a vertical axis O, a little excentric, so that the exterior portion is greater than the other; by the effect of the velocity of the train itself, which is almost always greater than the parallel component of the velocity of the air, this flap takes, for the direction of the running of the train, shewn by the arrow, the position A, A, and for the opposite direction, the other extreme position B, B. It thus forms a screen, which keeps the external air from passing in through the opening; in consequence of the vacuum which tends to be constantly produced behind the flap, it is on the contrary, the air out of the carriage which is drawn up, and replaced by the air which comes in through the other openings, fissures, and so on; a register *r*, allows the draught to be regulated at will.

56. *Double roof.* — Of all methods, the most efficacious, is the use of a double roof; the movement itself of the vehicle, produces between these two covers, a very active current of air, and consequently, a powerful draught, through the openings made in the lower roof. But this method has the drawback of being costly, and involves a loss of height of at least $0^{ft},33$.

Thus its application is restricted ordinarily to very hot countries, India, Egypt, Algeria (P, P′, *figs.* 2, 7, 10, Pl. III), Spain, and so on, in which it is not only required to ensure an active ventilation, but also, and above all, to screen the roof from the direct action of the solar rays. It is found, however, in some carriages destined for temperate climates, M. *Reifert's*, for example (P, P′, *figs.* 2, 3, Pl. V).

The spaces above the glazed frames, are sometimes provided with an opening, covered externally with venetians, protecting it against rain, and internally by a thin board pierced with holes (*o*, *o*, Pl. III, *fig.* 1; Pl. V, *figs.* 1 and 2; Pl. VII, *figs.* 1 to 3), which a register, placed between the board and the venetians, allows to be more or less open. This register is moved along by a button, which slides in a horizontal groove made in the board. The air can be thus renewed, without letting down the windows,

which it is sometimes necessary to keep shut, even when the weather is hot, to keep off the wind, and above all the dust, sometimes most annoying where the ballast is very fine.

The dust is in summer a very serious annoyance on many lines in the United States, on account of the bad quality, or rather of the total absence of ballast. It has been tried to get rid of this annoyance, on the *New-York and Erie line*, by purifying the air before letting it into the carriages. The windows are kept shut; the air is taken in by a windsail arrangement like that on board steamers, and passes through a reservoir, in which the dust is precipitated by an injection of water out of a rose nozzle. The water is raised by pumps worked by one of the axles.

We have already said that our plan does not comprehend the study of all the details of carriage bodies and their accessories. We shall therefore confine ourselves to the preceding observations on their arrangements.

§ VII. — **Special vehicles run in passenger-trains.**

This class includes: luggage-vans, carriage-trucks, post-office vans, horse-boxes.

57. *Luggage-vans.* — It is in this van that the head guard installs himself, to take charge of the luggage and parcels, and also to superintend every step required for safety in case of mishap, or accident. This official ought to have easy access to the engine-driver, with whom he communicates, while the train is running, by means of a cord fastened to a bell at the tender. This van ought to come next to the engine.

The converse arrangement, which, by the way, soon disappears as the stock is renewed, exists only on the southern section of the *Méditerranée* system: the head guard is posted in the end van.

The vans do not really differ from closed goods-waggons (118). The "Eastern" of France company has had vehicles constructed with two objects, to run either in goods-trains with the normal load of 10 tons or in passenger-trains, express or others with a variable, but always much smaller load of luggage. The bodies of these vans are, by exception, entirely of iron, as are also the frames. It is, moreover, now several years since the "Eastern" of France adopted iron for all its vans, with much reason for being pleased with the step.

In England, are found composite carriages having a compartment of greater or less extent for luggage, and intended for the improved service of branch lines without changing. The carriages for running on these branches, carry their passengers and their luggage, and are coupled on in suitable order, at the end of the main-line trains. The train slackens speed before coming to the junction, the end carriage is let off by a special mechanism for uncoupling; the points are turned after the train has passed, but before the cut-off carriage, which is thus, without loss of time, run on to its own line.

58. *Look-outs in vans and carriages. Their position.* — The luggage-vans are always provided with brakes. We shall take up later these details: but it is convenient to examine at this stage, the position occupied in the vans and in the carriages, by the guards and brakesmen who work these apparatuses, according to the signals given to them by the driver, and conveyed by the whistle of the engine, to watch the progress of the train, and to exchange signals, either with each other, or with the permanent way men. Their seat is ordinarily placed, with this object, at a height which enables them to see over the train more or less fully. On some lines, however, the *Rhine*, for example, there are no raised look-outs. It is objected that the steam, the ashes, and the rain, dirty the glasses, and intercept the view.

For the vans, the access to the look-out is always from the inside (Pl. XIV, *figs.* 1 to 4), unless in those which have to be sealed by the custom-house (Pl, XIII, *figs.* 1 to 3 and 4 to 6). The same sometimes occurred in the old brake-vans. A small compartment was specially devoted to the brakes. There was therefore a special arrangement in those vans. Now-a-days, the look-outs are always on the outside, so that the bodies of the vehicles with brakes do not differ from the others.

The outside look-outs are, besides, established under different conditions. On the *Western* of France, on the *Orléans* system, on the *Bourbonnais* line, on the Italian railways, and so on, they are reduced to a sort of small cab, open in front, and often even with the seat uncovered, placed in the middle of the carriage, and accessible from each side by an arrangement of steps. But in spite of this double access, the waggon has to be turned at each end of its journey, as the want of shelter requires these look-outs to be behind. Look-outs projecting over the end of the van, in which the guard, seated sideways, is protected by glazed sashes, are more in use. The box being indifferently either in front or behind the van, no turning thereof should

be required; the look-out, open in front and closed behind, has only one access into it, so that if it happens to be with its back to the platform, the guard has to pass round the train or get over the buffers, in order to take or leave his place. Although closed behind, the look-out could be rendered accessible on both sides of the vehicle, and thus avoid a palpable inconvenience; but it is never so; in fact, the vans or brake waggons with look-outs, accessible only from one side, placed in the centre or not (Pl. III, *figs.* 1 to 3), are always turned so as put the entrance of the look-out against the platform. There is no exception, but for short journey trains, which are not broken, and made up again at the ends; in one direction then, the look-outs are with their backs to the platform, a position which is, at any rate, more convenient in another respect, as to the signals made to the guards by the permanent way staff.

It is at times (I, 296) necessary to turn a brake-van, independently of the position the look-out may happen to be in. This case occurs when two of them follow each other, look-out against look-out. They project, in fact, too much, and so might damage each other, the buffer-blocks being insufficient to protect them.

Double access naturally exists, when the look-out has a cross-seat, and is in the middle of the van. The " Eastern " of France van is an example of this arrangement; instead of being open, at least in front, as in those quoted just now of the "Western" of France, the *Orléans* line, and so on, it is completely closed, and provided with two side-doors.

In American stock, and that derived therefrom, that is to say in all carriages entered by the ends, it is natural to utilise for the guards post, the platforms necessary for the passengers' access. There are not in that case any special look-out boxes. The guards stand on the platforms, and can when required, look along the whole train, by getting on to the steps (Pl. I, *figs.* 1 to 8 and 9 to 11; Pl. III, *figs.* 1 to 6; Pl. V, *figs.* 1 and 2; Pl. VIII, *figs.* 1 to 6 and 8 to 12).

Beyond this particular case, the look-out, outside and at a height up, is the best arrangement. As to their comfort, that is a matter of climate. If a plain seat without shelter is considered the best way to prevent the guards falling off to sleep, and to ensure their hearing the driver's signals better, still the position must be tenable. In winter, for long night-journeys, such would not be the case, even in temperate climates, on the lines of Strasburgh and Mulhouse for example. If the want of shelter is thought to be made up for, by an increase in coverings, the prompt handling of the brakes is not so ensured. A guard bound up in thick clothing has his movements

impeded thereby, and the access to his look-out, sometimes awkward enough, becomes difficult and dangerous for him.

When all are agreed as to the necessity of a shelter for the driver and stoker, already sheltered and warmed by the engine, it surely cannot be fair to refuse the same indulgence to the guards, subjected to much longer journeys, and whose position in winter, is often trying. As to the objection on the score of dirty windows, that can readily be met, by requiring the guards to clean them as often as necessary. Useful against cold, the shelter is not less so against heat. Its arrangement may even be altogether with reference to the latter. Thus the look-outs of the Algerian vans are provided with a double-roof p, p', and a broad screen o, o', which protects the guard from the force of the sun (Pl. XIV, *figs.* 1 to 6).

59. *Carriage-trucks.* — The development of the various systems of lines, has greatly reduced the number of carriage-trucks; ordinary road carriages rarely now come on the railways. Thus on the whole "Méditerranée" system there were no more on the 1st January 1869 than 118 of these trucks, which can always, by the way, be replaced by simple platforms. They are all four-wheeled. The carriage on its wheels, is kept in its place by straps, and by pressure blocks tightened by screws, applied against the tyres of the wheels.

60. *Post-office vans.* — Speed, frequency and relative regularity, with a gratuitous service, not by right but in fact, are not in France the only advantages offered by the railways to the important department charged with the transport of letters. Having gratuitously: 1st a daily train in each direction, the times of departure and arrival of which it fixes in concert with the traffic departments of the railways; 2nd in every other train, an ordinary carriage replaced at need by a special vehicle (art. 56 of the schedule) (*), the Post-Office is thus possessed of means of communication, infinitely greater than those of the old diligences. It has the facility, instead of simply accompanying its bags, as on the roads, of transporting with them a numerous staff, and so to utilise the time occupied by the journey, in the operations preceding the delivery of the letters.

By the terms of the schedule, the Post-Office constructs at its own expense as it thinks proper, the bodies of the carriages specially destined for its

(*) This of course is in France.

service. As to the rest, the frames and supports, the railway supplies and maintains those : a division which quite naturally results from the functions of each, and the responsibility incidental thereto.

The inside arrangements of the bodies has, however, produced frequent remonstrances from the companies; the absence of stuffings, the numerous sharp angles and edges presented by the pigeon-holes and racks, the presence of loose seats, movable lamps and stoves, the position of officials who work a great deal standing, are of a nature to greatly enhance the effects of certain accidents, such as slight collisions, breakages of axles, and so on, as affecting those employed in the vans. Post-office servants have been in effect hurt, where neither the passengers nor the railway officials received the slightest injury.

These less favourable conditions may be looked upon as one of the professional risks which have to be put up with; but the remonstrances of the companies have reference to the legal responsibility, frequently endorsed by the courts, which is desired to be placed on them in cases of accident. They maintain that their responsibility ends where their action ends, and that the consequences cannot be imputed to them, involved by vehicles, which, however irreproachable from the point of view of their special object, are eminently defective from the point of view of safety to those travelling therein, as well as loaded with obstacles which are particularly avoided in passenger-stock, as much from reasons of safety, as of comfort.

If this reasoning be plausible, it is fortunately almost theoretical, on account of the rarity of accidents : If the dangers presented by sharp edges, such as those of the letter-racks were really serious, the companies would take care not to put as they do, tables in the *coupés*. These tables would be likely to cause great injuries in a collision; if they are tolerated, then, it is because the excellent organisation under which the traffic is worked has remarkably lessened the chances of collision.

The conditions under which the most useful service of the travelling-vans is carried on, involves some consequences of which it is well to speak, on account of the influence they may exert, if not on the safety, at least on the regularity of the trains. The schedule (art. 9) fixes at 8 tons, the total maximum weight, including the load, of the vehicle of the Post-Office. The authorities of that department have no great interest in exceeding that weight in their daily train, because there the number of trains can be increased; but it is not the same as to the other trains where they have only the right to one carriage without charge. The "Méditerranée" company having established a train between *Paris* and *Marseilles*, which by its ra-

pidity, as well as by the hours of its departure and arrival, offered greater advantages to the Post-Office than the ordinary trains, and that department was naturally led to make more use of the quick train than of the latter. The regulation limit of weight was soon exceeded. The company, touched in its legitimate interests, and bringing forward considerations as to technical working, which had their part in fixing the maximum, complained. Not liking to add a carriage, the running of which would have had to be paid for, the Post-Office had recourse to an expedient, if not to be within the regulation limit, at any rate to reduce the excess. The travelling post-offices running on that system of lines were six-wheeled, and these were replaced by others with four wheels. But, under the pressure of the business to be done, the load could not be reduced as it ought to have been; so that this anomaly was encountered: the quick train, taking Post-office vans with more considerable loads than those of the slower trains (such as those on the Bourbonnais lines, for example), and running on four wheels, while the others have six wheels. The contentions provoked by this state of affairs are not our business; but we may note one of the material consequences thereof, frequent heating of the axle-boxes, and the necessity of cutting off the vehicle, and transferring its load.

The heating of the boxes was less besides the consequence of the exaggeration of the *total* load, than of the load on a single axle. With a considerable load, the exigencies of service scarcely admit of a good stowage. The officials have a difficulty in avoiding the accumulation, towards the end of the van, of a great number of bags, and consequently a very unequal distribution of the load. It is from this point of view especially, that the addition of a third axle is useful, as a means of avoiding accidental overloading, more or less prolonged. This addition has, in effect, put an end to the boxes heating.

It is not then sufficient (and to this especially we wish to come, in entering into these details) to fix the total weight of the travelling vans, seeing that they are subjected to notable inequalities in the distribution of their weights. It is also and above all the maximum weight per axle that should be fixed, and verified by weighing on the weigh-bridges. The Post-Office objects, with good reason, that the few minutes previous to starting are of the greatest value, and that it would be impossible to prohibit any addition to the load, once the van is placed in the train. Most certainly; but these last additions to the load should be made, as is easy, to be done in such a manner as not to interfere with the distribution on the axles, if the weigh-bridges have shown that the limit has been nearly reached.

Let us add, without insisting on the point, that the difficulty has arisen particularly from the extension given to the conveyance of small parcels by post, and to the influence of that on the weights of what are called letter-bags. A reasonable limit assigned to transports of this nature (a limit would be the immediate consequence of a pretty low maximum weight fixed for these parcels) would be the real true remedy for the evil; and at the same time a just satisfaction to the companies, who as may be imagined, put up with a bad grace with the competition of the Post-Office, in their parcel department, which beats them in this matter, with the very weapons they have placed at its disposition.

61. *Carriages of horses.* — Horse-boxes are arranged in two ways: the stall lengthways, or across.

In the first type, which was long the only one in use, the waggon only contains three stalls.

During the Crimean war, the question of the transport of horses was carefully studied. The horse-boxes, of which the "Méditerranée" system only now has 165, only formed an insignificant item in the face of the mass of transports to be effected. The cattle trucks alone offered sufficient resources. These were adopted, and with success; it was found that at the end of a long journey, the horses are much less fatigued, less disturbed, when they have been placed crossways than longways of the train. There is even an advantage in packing them in rather tightly one against the others; they support each other. But this juxtaposition, useful for army horses, which are generally calm, would be inadmissible with gentlemen's horses which are often highspirited. These ought to be separated by stuffed partitions. The arrangement crossways has only been adopted on the new horse-boxes of the "Méditerranée", which contain five or six stalls.

62. *Conveyance of dogs.* — In railway-matters there are no small questions; or at least there is no question which is small to every body.

The owners of dogs, for example, see no reason why this matter should be treated lightly.

If railways have in a striking manner simplified and improved the material conditions of conveyance of every sort, it must be owned, that dogs only, have gained little by the change. Admitted, or at least tolerated in diligences, they are stowed away on the railways in kennels in the luggage-vans (N, N, Pl XIV, *figs.* 1 and 2) in which animals of any size must be very

uncomfortable, and they prove it by howls and whines, which sometimes try the patience of their masters not to say the rest of the train. For them there are no classes, and the aristocratic dog cannot help being in contact with the humble watch-dog.

An official regulation (art. 67 of the rule of the 13th November 1846) allows passengers who do not wish their dogs to be separated from them, to have these with them in special compartments; this indulgence is frequently taken advantage of during the sporting season; indeed it is quite a necessity on some occasions when the accommodation of the luggage-vans would be quite insufficient.

The conveying of dogs in the vans, gives rise sometimes to loud complaints. It is, especially, crowding together into one kennel, animals of very different sizes, which causes this; and it might be easily avoided, as there are generally two luggage-vans in every train, with at least two kennels, and sometimes four : and rarely would that accommodation not suffice. The number of compartments could even be doubled, by dividing each of them by a partition : this is what was done originally, but is now given up on some lines (on the "Méditerranée" system for example). The partition, intercepting the air, is said to do more harm than good to the animals. This reason may be or not all right, according to the cases; it is a question of temperature.

A more serious objection against the division of the compartments is, that one of the halves opens on the wrong side of the line, which is the more objectionable, as many passengers desire to see their dogs put in themselves.

There is no means of giving an entire kennel, at an increased fare to those dogs desired by their masters to travel alone; for the conveyance of dogs together is only done, when the available compartments are insufficient.

The conveyance in baskets or cages, as parcels, is a solution as regards small animals. Perhaps, the prohibition of dogs in the carriages, might be relaxed in favour of small pet dogs. These little creatures are in no way troublesome; and when one sees with what motherly care their mistresses try to conceal them, with what eloquence they endeavour to talk over the officials when their attempt has been discovered, to escape the horrible kennel, it seems as if one might shut one's eyes a little, and not put the *King Charles* in the same category with the bull dog or Newfoundland. It is true that the line would be difficult to draw.

§ VIII. — Frames.

63. The frame ought to supply the body, which is fastened to it by means of straps and bolts *e*, *e*, *e*, (Pl. I, *figs.* 2 and 5) with a solid base, rigid notwithstanding its overhanging, and to the guard-plates (80) a perfectly invariable position. But the conditions of resistance, which it should comply with, result at the same time and in a great measure from the actions which the vehicles of one train exert one on another, in the sudden changes of velocity, when the frame is subjected to these actions; the details of its construction ought then to be proportioned to the mode of connection of the vehicles with each other, a point which we shall look into further on (125).

The frame, like all the rest of the vehicle moreover, fulfils an important function by its weight, which is an element of stability. In goods-stock, its relative lightness can and ought to be considered; every reduction in dead-weight, not obtained with the sacrifice of solidity, durability, cost of maintenance, is a progress. But it is not the same thing with regard to the passenger-stock (27). It should not therefore be wondered at, that the frame in these, enters for such a large share in the total weight.

For example, the weight, of an English composite carriage with four compartments, two first and two second, 24^{ft} long, weighing altogether $7^{tons},166$, is thus distributed:

	Tons.
Body	2,94
Frame	2,14
Springs	0,33
Axle-boxes	0,13
Wheels and axles	1,62

At present frames are usually made of wood. They are formed (Pl. X, *figs.* 1 to 4) of two longitudinal pieces L, L, two end cross-pieces T, T, intermediate cross-pieces *t*, *t*, and two diagonals crossing each other A, A, tying the whole together, according to the general principle of the division into triangles. The two diagonal cross-pieces, which are flat, are flush with the top of the frame, they thus leave below them, the space necessary for the springs (125), and add to the support of the floor of the body.

Sometimes, however (Eastern of France, Pl. II, *figs.* 1 to 4) the cross diagonals are placed under the frame, and their ends slightly curved up butt

against the end transoms. They thus stiffen the frame, which cannot give without bending and compressing them, and their being fastened to the intermediate cross-pieces, gives solid points which help them in resisting this action.

The breadth of the bodies, although in some cases only that of the frames (Pl. VII, *fig.* 11, Norwegian stock) is generally much greater, particularly in the vehicle with a longitudinal passage, without side-doors. The unsupported portions of the body, are in that case carried either by prolonging the underbeams as in Mr *Reifert's* carriage or by brackets rivetted on to the front side of the longitudinals (New carriage, *les Dombes* line, Pl. VIII, *figs.* 1 to 3).

The independence of the frame of the body, simply placed on it and fastened to it, may seem defective in certain respects. To consolidate them, making the body stronger, would make the whole into a sort of open girder. The metal carriage (44) of the "Indian Branch Railway" is in this case. The same conditions are to be found in many goods-waggons (147) and in rolling-stock of the American type; but it can be understood why this system is not extended in use. The independence of the two has in effect on its side certain advantages. It simplifies maintenance and repairs. Passenger-carriages with their numerous lateral openings, are very unsuited besides to the construction of a sort of open girder: the contrivance applied by Mr *Wilson* to the Indian stock, that is to say, the introduction of small bays B, B, B, in the trellis openings (Pl. II, *fig.* 10), being impracticable for bodies with side-doors. On the other hand, the substance of the carriage ought to be concentrated principally in the frame, especially if subjected to the strains which result from the mutual action of the vehicles on each other (125) and not in the roof, so that the distribution is very different to what would be the case in a well proportional girder.

For a long time, one single frame for the different classes of vehicles was kept to. It is doubtless well, in general, not to multiply types, but nothing should be exaggerated. In a large stock there is no objection to having two or three patterns of frames for carriages; and a uniformity of frames presents a very serious drawback: the bad internal arrangement it would lead to for one if not two of the three classes.

64. *Frames in metal.* — In face of the constantly increasing price of sound and seasoned oak, required for frames, the equally increasing dimensions of the longitudinals, and the reduction in the price of iron, it is asked why the use of the latter is still so little extended, particularly in France.

It is really only just commencing to become general. The combination of iron with wood in distinct pieces, seems to have no good grounds. In the shape of strengthening-pieces, the partial adoption of iron is more satisfactory. In this way on the "South-Eastern", the wooden longitudinals are stiffened by a thick plate of iron outside. On the *London, Chatham and Dover*, a stout iron strap is let in, for its thickness into the side of the longitudinal to which it is bolted; it is curved downwards, in such a manner as to act as a tie of a beam. The waggons constructed by Mr *D. Clark* (Pl. X, *fig.* 10) present another instance of the partial use of metal. Longitudinal and transverse tie-rods, screwed *t, t, t,* tie the woodwork together, and allow the ordinary iron-work to be dispensed with.

In France, the Railway Department has, indirectly, urged on the companies the adoption of iron-frames, in consequence of some cases of fire. Pieces of fuel out of the fire-box, thrown up by the spokes of the wheels and lodging in the sharp angles of the frame, can set it on fire, which from the rapid current of air caused by the running of the train, may easily catch to the flooring of the body. This is particularly to be feared, when careless cleaners have left in some of the angles, the cloths they have had to clean with. The following order of the "Méditerranée" company, has for object to put a stop to such culpable carelessness :

1. It is reported from several points, that carriage cleaners, examiners and others, have the objectionable habit of leaving on the frames of the carriages and waggons greasy cloths which have been used by them for cleaning.

Recently, cloths thus left on the frame of a carriage were set a light to by a spark, and might have caused a serious accident, if it had not been discovered in time.

2. In order to avoid all forgetfulness of this sort which causes danger, it is formally prohibited, particularly to greasers, examiners and others, to put down even temporarily, during their work, greasy cloths or any others, either in the carriages and waggons, or outside on the frames or foot-boards; the cloths dirty or clean, ought during or after the work, to be deposited in the pails or boxes intended for them.

3. The greasers and examiners must most carefully see to the carrying out of the preceding clause; they will remove from the waggons or frames, all the cloths which may have been left therein in spite of these instructions, and will point out with the greatest care, to their foreman, all infractions, which will be duly brought to the notice of the engineer.

4. The neglect, or infraction of the instructions given in Nos 2 and 3 will be severely punished.

5. The district-superintendants, and the locomotive authorities are charged, in so much as concerns them : 1. to bring the present order to the knowledge of those of

their subordinates who may have to carry it out or see it carried out; 2. to see that it is carried out.

Paris, 3rd February 1866.

The position of passengers surprised by fire in a train running is most critical, particularly in expresses, which run long distances without stopping.

It is partly to obviate the consequences of accidents of this kind that a means of communication between passengers and the officials of the train would be useful. But the Railway Department has called upon the companies to take measures to prevent such accidents occurring at all. On the "Eastern" of France, it has been decided to protect each piece of the framework by a sheet of iron. On the "Méditerranée", a sheet of iron completely isolates the frame from the flooring of the body. The propagation of fire to the frame is thus impossible, and the frame is thus in reality protected also, as fire is unable to attack it, excepting under the action of the intense draught produced by the fire breaking through the planking.

But the most direct as well as most thorough solution, is evidently the complete suppression of wood in the frames; and as other advantages are admitted to result from this, it commences to be adopted, or rather to be readopted (Pl. I, *figs.* 1 to 4; Pl. II, *Figs.* 5 to 8; Pl. V, *figs.* 1 to 3; Pl. VIII, *fig.* 3).

On some lines however, wood is systematically adhered to. On the *Orléans* system for example, they stick to wood, "with the object of deadening vibration". It seems difficult to admit the grounds of this motive. Doubtless there are some proportions with which iron would spring more than wood; but with others it would be the reverse. In fact with the external dimensions, and sections in use, iron is certainly more rigid, and it does not vibrate more, if it does not vibrate less. Carriages with iron frames run now in the express from *Paris to Marseilles*, and the most sensitive travellers would be puzzled to discover the least difference in the way of these carriages run, from those with wooden longitudinals.

This application of iron is not new: far from it. As is often the case, it was brought into disrepute through some ill conceived trials, and inconsiderate views. As far back as 1842, Mr *Brunel* employed iron frames on the "Great Western". The first carriages on the *Greenwich* line had the same. Mr *Gooch* built, twenty years ago, for the "Eastern Counties" (now the Great Eastern) carriages with frames in iron weighing $2^{\text{tons}},2$, the same as the wooden ones.

The most frequent objection was the greater seriousness of the damage in case of shocks. The disturbance, it was said, would be more general. It is quite the reverse. In Germany, a more lengthened experience of this mode of construction has shown that the damage is more localised, and consequently easier to repair. The preference to be given to wood or to iron, is altogether a question of economy. The sections of the different pieces of the frame are scarcely calculable, on account of the indetermination of the strains to which they are subjected to. It would be right, in case doubt, not to be sparing of material at first, as reductions can always afterwards be made, if experience shows excess. Weight is besides, we repeat once more, an essential element in carriages. Thus up to the present time, iron frames are made as heavy, and even a little heavier than the wooden ones. On the "Eastern" of France the excess in the weight of the carriages with iron frames is : for first class, 11^{cwt}; for the second class, 9^{cwt}, and for the 3rd class, $12\ 1/2^{cwt}$; but these differences do not amount to one half, with respect to the frame. On the "Méditerranée" system, the excess due to the frame alone is about 4^{cwt}; and the price is also a little higher, about £ 8.

But under these conditions, economy is most certainly in favour of iron, on account of its much greater durability, its resistance to deflection, and indeed to all strains.

The cross section of the elements, longitudinals and cross-pieces, are derived, naturally, from the double T, a form indicated by what these pieces have to do, and which for the longitudinals offers broad enough surfaces for their bearing on suspension springs (70). To the double T proper, sometimes a U iron is preferred, which simplifies the connections. The "Eastern" of France on the contrary prefers the double T; but it is on the ground sometimes urged, that the guard plates, let into grooves on the lower flange, are better fastened. *Fig.* 7, Pl. II, shows in effect, that to avoid either narrowing the frame, or increasing the length and consequently the overhanging portion of the axle, the guard plate is applied against the edges of the flanges of the double T, being the projection of these flanges made up for by small blocks bolted on.

On some English lines, on the *London*, *Chatham* and *Dover*, for example, the section is a simple T, with the flange upwards.

§ IX. — **Suspension of the bodies.**

65. Notwithstanding the relative perfection of the permanent way, suspension is not the less necessary for railway rolling-stock, than for that which runs on common roads. The velocity compensates, in fact, for the advantages of the smoothness of the rolling surface. Indispensable for passengers, suspension is so favourable to the preservation of the stock, that it is always now applied even to goods-waggons, notwithstanding the slow speed at which these generally run.

When the vehicle is rigid, the whole of its mass is subjected to the inequalities of the road. With springs placed as close as possible to the shocks, that is to say on the axle-boxes, the mass producing the shocks is reduced to that of the wheels and axles. The wheels pressed by the springs follow the unequalities of the road, instead of separating therefrom, to fall down again and then separate afresh; within certain limits, the movement of the body is not affected, at least directly, by what passes under it; the wheel in passing over an obstacle, such as a rise at a joint, rises by lifting the spring, which afterwards springs back, keeping the wheel on the rail, and only affecting the body by long consecutive undulations. The importance of the functions of the springs increases still more when the elasticity of the ballast is reduced by frost. In Norway, Mr *Pihl* states that he has effected a notable reduction in the breakages of axles and even of springs by putting in between the latter, and the axle-boxes, sheets of vulcanised india-rubber (73). Mr *Sinclair* also employs these on the "Great Eastern", where they seem to assist the springs.

66. *Springs of one simple plate.* — The spring placed on its middle, upon the axle-box, or, more rarely, hung therefrom (Pl. V, *Fig.* 4), receives the load at its two extremities, from the longitudinals. Springs of one single plate have been employed in Germany, on, among other lines, that from *Berlin to Stettin.* Above the plate was another, short and much curved, or auxiliary, coming into play only in the case of large oscillations, or the breakage of the main plate. This spring was given up because of the difficulty of tempering a bar of unequal thickness, and which was obliged to be of considerable mass, in order to fulfil the given conditions of resistance and flexibility.

This spring, in one single piece, has, besides, the drawback incidental

to one simple piece, that is to say, the rejection of the whole, in case of breakage.

The plate should have a parabolic profile, a form doubly advantageous in this case, on one hand by the saving of one-third of the material, and on the other hand, and above all because the live resistance is doubled for the same maximum molecular effort R.

It is easy to see, in effect, that a bar parabolic in side elevation, absorbs for the same amount of deflection, twice as much work, as one of uniform thickness. It has been shown (I, 337) that this work is expressed approximately by $\frac{1}{2}$ (2 Pf), 2 P being the statical load applied at the centre, corresponding to the strain R, and f the deflection due to that load.

$2a$ being the length of the plate (Pl. VII, *fig.* 16), b its width, c its thickness, I the moment of inertia of the cross section, the molecular effort R in the extreme fibres of the section, the absciss of which is x, is: $R = \frac{VP}{I}(a-x)$; and for a rectangular section:

$$R=\frac{6P}{bc^2}(a-x). \qquad (1)$$

One of the quantities b and c, or both, ought to vary in such a manner as that R may be constant.

The equation of the moments is:

$$\frac{E}{12}bc^3\frac{d^2y}{dx^2}=P(a-x). \qquad (1)$$

(1) gives $\quad c^3=\frac{6P}{Rb}(a-x)\sqrt{\frac{6P}{Rb}(a-x)}$; carrying into (2),

$$\frac{E}{2R}\frac{d^2y}{dx^2}\sqrt{\frac{6P}{Rb}(a-x)}=1, \quad \text{whence} \quad \frac{d^2y}{dx^2}=\frac{2R}{E}\sqrt{\frac{Rb}{6P}}(a-x)^{-\frac{1}{2}};$$

integrating,

$$\frac{dy}{dx}=\frac{2R}{E}\sqrt{\frac{Rb}{6P}}\left\{-2(a-x)^{\frac{1}{2}}+2x\sqrt{a}\right\}$$

$$y=\frac{2R}{E}\sqrt{\frac{Rb}{6P}}\left\{\frac{4}{3}(a-x)^{\frac{3}{2}}+2x\sqrt{a}-\frac{4}{3}a^{\frac{3}{2}}\right\},$$

and making $x = a$,

$$f=\frac{4R}{3E}\sqrt{\frac{Rb}{6P}}\cdot a^{\frac{3}{2}}. \qquad (3)$$

Now c_1 being the thickness at the middle, or for $x=o$, we have $c_1 = \frac{6Pa}{Rb}$, whence

$$\sqrt{\frac{Rb}{6P}}=\frac{\sqrt{a}}{c_1}; \text{ substituting in } \qquad (3)$$

$$f=\frac{4R}{3E}\frac{a^2}{c_1}. \qquad (4)$$

While for the solid of uniform thickness c_1,

$$f=\frac{1}{3}\frac{Pa^3}{PI}, \quad \text{or because of} \quad P=\frac{IR}{Va}, \quad \text{and} \quad V=\frac{c_1}{2},$$

$$f=\frac{1}{3}\frac{Ra^2}{EV}=\frac{2}{3}\frac{Ra^2}{Ec_1},$$

a value affected it is true, by a special cause of error, the axis of the solid unloaded not being rectilinear, as in the case of the prism. But in practice, the curvature of this axis is not sufficient to have any appreciable effect on the result.

The form of equal resistance doubles then the flexibility.

From the expressions:

$$f=\frac{4}{3}\frac{R}{E}\frac{a^2}{c_1}, \quad (4) \qquad P=\frac{IR}{Va}=\frac{1}{6}\frac{Rbc_1^2}{a}, \quad (5)$$

is deduced

$$T=\frac{1}{2}(2P)f=\frac{2}{9}\frac{R^2}{E}abc_1.$$

Now the volume U of the plate is:

$$\frac{2}{3}(2a)\times b\times c_1; \qquad \text{then} \qquad T=\frac{1}{6}\frac{R^2U}{E}=kUk$$

k being a number; the law already indicated (I, 337) for the plate with a constant section. The work to absorb, that is to say the maximum load and the corresponding deflection being given, the volume of the plate is thus deduced. One of the three dimensions a, b, c_1, can be taken arbitrarily; the two others are deduced from equations (4) and (5). If for example a be given, we have:

$$c_1=\frac{4}{3}\frac{Ra^2}{Ef}, \qquad b=\frac{27}{8}\frac{E^2P}{R^3a^3}f^2.$$

Thus if it were desired to make the length of the plate $2a$ small, the thickness at the middle c_1 would be also small, but the breadth b very great.

67. *Springs of separate plates, of the same length.* — While adhering to the principle of the parabolic form, the division of the plate into portions reduces the disadvantages of that spring. It is then formed of several plates one above the other, all having the section of equal resistance, and of the same length. They transmit the load by turned-up pieces at the ends, and the excess of height thus given to each plate is made up at the middle by packing pieces.

The clip is fastened, not to the main plate, but to a jointed bar, so that

the main plate is no more exposed than the others to the longitudinal tension arising from the obliquity of the clip (70). The jointed bars which may be placed either above or below the springs at will, may in the first case, take on their own account a portion of the load, whenever, by the deflection of the spring, it goes below the horizontal line passing through the middle of its length, and it thus limits the strain on the plates. They carry besides at each end a fork which catches the ends of the plates, and prevents their spreading out sideways.

The equality of resistance of the plates one over the other can be effected by variations of their width, instead of their thickness. This form, little used, has been adopted by Mr *Wilson*, for the suspension of the carriages and waggons of the *Oudh* and *Rohilkund* lines (ρ ρ, Pl. II, *fig.* 11).

68. *Springs with plates diminishing in length.* — Greatly used for some years in England and Germany, springs with plates of the same length and not joined is now given up. They have given place to springs with plates joined together, and of decreasing lengths, in long use in ordinary carriages.

Formed of plates with small cross dimensions, which are placed one over the other in greater or less number, this system fulfils in a sufficient degree, the general condition of working the material: that of equality of resistance. It is easy in effect to determine these elements, in such a manner that under a given load, and of course the maximum load is taken, corresponding to the flattening of the spring, the molecular tension of the extreme fibres may be nearly the same, in all the cross sections of one plate, as well as in all the plates, which bend unconnectedly, each of them having its own neutral axis.

The theory of this spring, founded on the generally admitted principles of the resistance of materials, has been established by M. *Philips*; I shall content myself with referring the reader to that work (*), and to give here, in the most simple form, a few considerations, which will be found sufficient for the practical determination of springs.

The given quantities are: 1. the maximum load $2P$; 2. the maximum molecular strain R due to that load, or the maximum proportional elongation i, which comes to the same, seeing that $R = Ei$; 3. the deflection f produced by the load; 4. the cross section of the plates. i must not exceed,

(*) *Annales des Mines*, 5th series, vol. I, 1852.

under the normal load, 0,002 to 0,003, and under the testing load, 0,004 to 0,005; values which correspond, for $E = 28{,}446{,}000$ to $R =$ respectively 25,4 to 38,5 tons, and 50,8 to 63,5 tons on the square-inch.

The elements to be determined are: 1. the length of the main plate; 2. its radius of manufacture, being assumed circular; 3. the sets-off, that is to say, the distances between the ends of the superposed plates; 4. the total number of plates, and consequently the thickness of the spring at the centre.

Let us suppose first, a straight plate, of uniform thickness c, placed on a mandril curved to the radius ρ (Pl. VII, *fig.* 17). The plate yielding to the load, rests for a certain distance of its middle portion on the mandril: throughout that extent the maximum molecular effort is: $R = Ei = \frac{EV}{\rho} = \frac{Ec}{2\rho}$; it is then constant.

It is the same thing if the plate, curved to a circular arc of radius ρ, is placed on its convex face on a plane, admitting, which is practically exact, that it flattens and lies along the plane in contact therewith for the whole length, it comprised between the two extreme points of contact C, C′ (Pl. VII, *fig.* 18). It is evident, in effect, that the state of molecular tension is identically the same, whether in the bar straight first, then deflected along the arc of radius ρ, or in the bar curved to that arc and then straightened by force.

This part which the imaginary mandril plays, but by paralysing the play of the spring the more it is loaded, the stepped plates fill, but leaving the system full freedom and satisfying, in the case of each, the approximate condition of equality of resistance.

69. *Determination of the spring.* — 1. *Main plate.* The spring has to undergo a deflection f, for the load $2P$. Suppose that, as takes place ordinarily, it is curved to an arc of a circle, and that it ought to straighten itself under this load $2P$; its camber of manufacture is then f.

This fixed, the relation $R = \frac{Ec}{2\rho}$ gives for the radius:

$$\rho = \frac{Ec}{2R}.$$

The length of the main plate is:

$$l = \sqrt{(2\rho - f)}\quad f = \text{nearly } \sqrt{2\rho f} = \sqrt{\frac{Ecf}{R}}.$$

2. *First set-off.* We have in M (Pl. VII, *fig.* 20):

$$\frac{EI}{\rho}=Pd, \qquad \text{whence} \qquad d=\frac{EI}{\rho P}=\frac{1}{6}\frac{Rbc^2}{P}.$$

3. *Second set-off.* Supposing at first all the plates to be curved to the same internal radius ρ, and of the same thickness c. We have in M′:

$$\frac{EI}{\rho}+\frac{EI}{\rho}=P(d+d'), \qquad \text{whence} \qquad d'=\frac{EI}{\rho P}=d,$$

and so on.

4. *Number of plates.* We have evidently:

$$l=nd, \qquad \text{whence} \qquad n=\frac{l}{d}=\sqrt{\frac{Ecf}{Rd^2}}.$$

5. *Law of increase of the thicknesses in the spring without original tension.* But, curved thus to the same radius, the plates when put together only rest on each other at the ends, and have a space between them at the middle. They cannot be brought into complete contact excepting by an effort exerted by the buckle or the bolt that fastens them together; the spring unloaded is thus in a state of tension, at the expense of its useful resistance. The plates cannot coincide freely without being curved to radii increasing successively by the amount of the thickness of the preceding plate. And seeing that the molecular effort, in the straightened spring is proportional to the ratio of the thickness to the radius, equality of resistance requires that the thicknesses themselves should increase.

c, c', c'', c''' . . . . being the successive thicknesses, the corresponding radii are:

$$\rho,\ \rho+c,\ \rho+c+c',\ \rho+c+c'+c'', \text{ etc.}$$

and we have

$$R=\frac{c}{2\rho}=\frac{c'}{2(\rho+c)}=\frac{c''}{2(\rho+c+c')}, \text{ etc.}$$

whence

$$c'=c\left(1+\frac{c}{\rho}\right); \quad c''=c\left(1+\frac{2c}{\rho}+\frac{c^2}{\rho^2}\right), \text{ etc,}$$

The second set-off d' is given then by the relation:

$$\frac{EI}{\rho}+\frac{EI'}{\rho'}=P(d+d'),$$

whence because of

$$\frac{EI}{\rho}=Pd, \qquad d'=\frac{EI'}{P\rho'},$$

in which I and ρ' are known quantities; and in the same manner for the following sets-off.

By increasing the radii more rapidly than the above law, the plates, in the unloaded spring, are not in contact excepting in the middle; under light

loads, the upper plates alone are strained throughout their whole length. The load increasing, they gradually in flattening come on to the lower plates, which come successively into play. This arrangement carried into effect like many others which we can scarcely examine in detail, has for limit the spring with *auxiliary bar*, a thick and consequently rigid bar upon which the spring rests at its middle portion, when it becomes accidentally overloaded; this spring is, up to a certain point, the realisation of the hypothesis set forth farther back (68), of the invariable solid, upon which the elastic body rests more or less in flattening. The part of auxiliary can also be filled by a special plate placed, not in this case under the spring, but above the main plate, shorter and much more cambered than that plate. This plate is ordinarily free; it is not come upon excepting in deep oscillations, by the longitudinal beam of the frame, which lodges on its ends.

Mr *Phillips* has determined by calculation the deflection of a spring with stepped plates, under a given load. This value brings out a remarkable analogy between the system in question, and the solid in one piece in the form of equal resistance. For the latter the deflection is double that which, with the same load, the prism would take, having for base the section at the middle. For the first the expression of the deflection is composed of two terms : one is the deflection of the spring, all the plates of which would have the same length, that of the main plate; the other is the deflection due to the sets-off only : this, besides, is much smaller than the first.

70. *Spring-clips.* — In passenger carriages, the longitudinals of the frame are scarcely ever simply placed on the ends of the springs; supports bolted or rivetted transmit the load to the spring by means of clips m', m', (Pl. I, *figs.* 1 and 7; Pl. XI, *fig.* 19), which get rid of the friction and leave the axles free to get the advantage of the play left by the guard-plates. With vertical clips this movability of the axle would be too great, and the body itself would swing like a pendulum, within the limits of the play left between the plates. This drawback disappears with clips placed at an angle; the connection, along the horizontal, between the body and the wheels, is thus complete enough for the axle to be drawn along by the springs, and the guard plates only become simple safety appliances.

The inclined clips were equally applied to springs with plates of equal length, and to jointed straps (67), and the guard plates the functions of which were assumed by these traps naturally disappeared. It is the same now with springs of plates of decreasing lengths when they are provided with a

system of ties. The guard-plates are thus reduced to a sort of collar or clip, placed on the side of the inner face of the wheel, surrounding the axle at a certain distance and intended to keep the wheel on, if the axle should break between the wheels.

The inclination of the clips gets rid of the small horizontal oscillations of the body in the direction of its length, and at the same time the conditions of the suspension itself are improved, if the spring keeps a marked camber under the statical load; the suspension is, in effect, so much the better the slower the undulations imparted to the body by the oscillations of the springs are, which precedes its return to a state of equilibrium, or at least within certain limits. Now Mr *Phillips* has shown (*) that the duration of the oscillation of the spring is proportional to the square root of the statical deflection (it is the same as that of the oscillation of a pendulum of a length equal to that deflection) with an inclination at an angle α with the horizon, the spring and the main plate are subjected, respectively, to a longitudinal tension $\frac{P}{\sin\alpha}$, $\frac{P}{\operatorname{tang}\alpha}$. This last augmenting the deflection, seeing that it tends to strengthen the spring, increases, of course, the duration of the oscillation, but its amplitude increases also.

This effect is in general little felt, at any rate in the usual carriage-springs, the camber of which is slight and pretty much disappears under the statical load; which presents, by the way, an advantage: the flatter a spring is, the smaller are the relative displacements of its plates, and in consequence thereof the more freely it plays.

71. *Examples.* — In England the camber given to carriage-springs in the manufacture is ordinarily $\frac{1}{30}$ of the length; and the flexibility per ton from $1^{in},75$ to $2^{ins},5$.

These are the elements of the bearing springs of the first class carriages of the *Paris and Lyons* by "le Bourbonnais"; section of the plates, $0^{in},39$ thick, $2^{ins},95$ wide; length of the main plate measured straight, $5^{ft},81$; camber of manufacture $0^{ft},46$. Number of plates, 10; flexibility per ton $3^{ins},15$; limit of testing load 2tons,88; corresponding deflection $0^{ft},75$. The springs of the second and third only differ by the number of plates, increased to 11, and by the flexibility, a little less, consequently $2^{ins},76$.

In the Algerian stock (Pl. III, *figs.* 1 and 6) the spring is composed of

(*) Paper quoted above, pp. 249 and following.

11 plates of the same section as the preceding. The chord and camber of manufacture are : $4^{ft},79$, and $0^{ft},45$, and the flexibility per ton $2^{ins},80$.

As details of construction, it will be sufficient to mention:

1. The thinning off of the plates, for the length of the set-off; this thinning the plates off renders the change in the total section less marked, at the end of each set-off. *Fig.* 19, Pl. VII, indicates the manner in which the thinning off of the plates is done on the "Western" of Switzerland, for the spring of a first class carriage, of which the following are the particulars: thickness of plates $0^{in},39$; length of the main plate measured flat $5^{ft},80$; camber of manufacture $0^{ft},61$; flexibility $3^{ins},74$ per ton; normal load, $1^{ton},47$; straightening load $1^{ton},93$; corresponding proportional elongations $0^{in},098$ and $0^{in}13$; step, $3^{ins}86$; number of plates 8; mean weight of the spring $92^{lbs},81$.

The reduction in the thickness is sometimes replaced by a gradual reduction in the width of the plates (Pl. XI, *figs.* 13 and 16).

2. Studs fastened underneath each plate, and sliding in grooves cut in the plate below, keep the plates fair one over the other; these studs are sometimes replaced by stirrups *b*, *b*, (Pl. IX, *figs.* 12 and 15), and oftener now-a-days by a longitudinal channel, hollows on the concave side of the plate, and projecting on the convex side, and done in the rolling. There is thus between the plates a partial hold, which answers the purpose better than the studs, as it is simpler and has at the same time the advantage of leaving the plates freer, while it does not weaken them by a groove.

72. The spring is ordinarily applied directly on to the axle-box to which it is solidly fixed. Sometimes however, in the Norwegian stock for example, an indian-rubber washer is put between them which is said to produce a very sensible influence on the ease of the suspension, particularly when the ballast is frozen deeply, and renders the road very hard for running.

On the "Northern" of France, the spring is attached to the axle-box by an articulation parallel to the longitudinal axle of the vehicle. It is easy to see the object of this arrangement. The axle, in taking positions inclined to the horizon, has no tendency to turn the spring over side-ways, and the load remains uniformly distributed over the bearing; but this complication which the play of the clips seems to render useless, has been recently given up : unbroken solidity of connection, which is the general case, presents no disadvantage.

On the same system of lines, the frame is attached by means of the clips, to the main-plate, as well as to a special shorter plate called the check-

plate, which maintains the connection in case of the breakage of the main-plate.

73. *Double suspension.* — The suspension of railway-vehicles is altogether analogous to that of ordinary carriages, and even less perfect than that of the most highly finished ones. For a long time they have sought to improve this, on the *Orléans* system of lines; the bodies of the first class are separated from the frames by india-rubber washers. The attachment to the frame is effected by means of screw bolts fixed to the body and passing through the washers as well as the supports thereof, bolted on to the out-sides of the longitudinals.

" This disposition, " says the company in a note on the stock exhibited in 1867, " has for effect, not to increase the elasticity of the hanging, but to prevent the transmission of the vibrations produced by high speeds. Adopted since 1855, it has been appreciated by passengers, and we have applied it successively to all the first class carriages. "

The influence of this detail does not appear very obvious; however the example of the "Orléans" company is now followed by the "Northern" and the "Western" of France, as well as by a certain number of English and German lines (*fig.* 40, Pl. XI, *Saarbrück* line). The boxes B, B, rivetted on the outside of the longitudinals are four in number, on each side. Some engineers think that the real effect of the arrangement in question is to deaden the noise of the vehicles. But it is above the shaking of the glass-windows which should be prevented, and the *Orléans* company considers the application of the direct method already pointed out (55) always necessary.

" We have equally " they say in the note just quoted " in spite of the increase of maintenance involved, kept to the use already of considerable date, of plush coverings to the sash frames of the glass-windows. Of all the means employed for deadening the deafening noise caused by their shaking, it is the one which gives the best results. "

A German constructor already referred to (29, 30) Mr *Reifert*, carries to a much greater extent the separation of the body and the frame by an elastic medium. He hangs the body from the frame by six springs ρ, ρ, ρ, (Pl. V, *figs.* 1 to 3, and Pl. XI, *figs.* 29 to 39) always of course suspending the frame itself on the axles. As the springs are unquestionably not sufficient to prevent the separation of the body and the frame, in sudden changes of velocity, the first is let in against shoulders E, E, in the platforms at the ends of the second, with a little play to allow the springs to act freely;

stops t, t, fixed underneath the body, and catching under angle irons f, f, rivetted to the frame complete the attachment.

The supplementary springs are placed, as they should be, in the line of the longitudinals supporting the flooring of the body. On account of the excess of width of the latter relatively to the frame, the springs ρ, ρ, are suspended at the extremities of small beams rivetted on to the frame (fig. 3). These carriages run very softly, very quietly. One can read in them and even write at high speeds, almost as if they were standing still; but this advantage does not seem marked enough to warrant the increase of weight and of price, and the complication involved by such an arrangement, already applied, by the way, to some saloon carriages; for example to two of the vehicles of the Imperial train of the *Orléans* company.

Double suspension is very common in the United States, but under a somewhat different form. The principal frame is hung on the frames of the bogey trucks, and the latter on the axles. When the distance between the axles is pretty short, the springs of the bogeys act as longitudinals; they rest in that case on the axle-boxes by their ends, which are bolted thereto. These springs are necessarily thus very rigid.

Double suspension is in general fully warranted by the state of the permanent way.

The Russian carriage represented by *figs.* 9 to 11, of Pl. I, offers an example of the arrangement in question, but with the addition of two small ties e, e, which connect the springs.

74. *Divers springs.* — Some constructors thought some years ago, to improve the spring with stepped plates, by inserting packing-pieces at the middle, on account of the plates being only in contact at the ends; but although this separation is warranted and even necessary with plates of the same length and of equal resistance (60); this in the case of the stepped spring, it was only a drawback. They believed, by a false assimilation with hollow solids of one single piece, that the resistance would be increased, by increasing the thickness; but in reality all that was increased was the chance of breaking the plates. Breakages were much more frequent than without the packing pieces, which were therefore soon given up.

We might also mention a trial made a long time ago at the *Verona* shops. The spring was composed of only two plates, separated in the middle, by a thick packing-piece, and solidly fixed at the ends. To this effect, the upper plate laps over the other, and a bolt fastens the whole. In this case, up to a certain point, this is a simple hollow solid, and with the longitudinal

profile of equal resistance, that is to say, placed, theoretically, in satisfactory conditions; but the fastening at the middle and at the ends is not sufficient to establish complete solidarity between the two, and thus insure unity of deflection. Very large dimensions, too, would be necessary to obtain from only two plates, the resistance required now-a-days. In any case the trial was without result.

In the locomotive where numerous parts have to be lodged in a restricted space, when the frame is inside the spring with plates one over the other is not always applicable. But it always is in the carrying-stock, and the attempts made to employ the elasticity of steel under other forms, have given but poor results. We shall cite as example, the spring of Mr *W. Bridges Adams* (Pl. XI, *figs.* 22 to 25). The elastic portion, or the spring proper, is formed of two curved plates L, L, widened at the middle, acting as curved solids loaded on end. This spring worked satisfactorily as long as the velocity was small; but at a high speed, too great a rocking of the body of the carriage was attributed to it. This was less without doubt, the necessary consequence of the principle, than of the dimensions. But a more serious objection arose from the complication of the spring, and from its position; it was too near the ground. As to the danger of a broken plate sticking into the ground, it was easy to get over that by a thin sheet of iron covering the spring in underneath.

Baillie's volute spring, often used for couplings (113) has been sometimes also adopted for bearing, for example, in Austria. The necessary resistance is obtained, by putting two or three springs together, and the desired flexibility, by putting when required one row of springs over the other. But the system is then more complicated and costly than the equivalent spring with stepped plates. This arrangement can only be justified by a necessity, which never arises in carriages and waggons.

§ X. — Axle-boxes for grease and oil.

75. The types of axle-boxes are innumerable. A German engineer Mr *Heusinger von Waldegg* has published their monography. It forms a thick volume in 4to (*). This is saying that no one of them is fully satis-

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(*) *Die Schmier vorrichtungen und Schmiermittel der Eisenbahnwagen*, by *E. Heusinger von Waldegg*, 1 vol. large 4to with 23 plates and 75 wood cuts in the text. *C. W. Kreidel*, Wiesbaden, 1866.

factory. The problem is in fact complicated. The vehicles make long journeys; the journals are not like the spindles of machinery, accessible at every moment, and constantly looked after. If it is difficult to keep in the lubricating material, to prevent it running out of the box, through the opening by which the axle enters, it is not less difficult to prevent from entering by the same way, dust, which forms a sort of atmosphere driven up by the running of the trains, especially when the ballast is too fine, and the weather dry. A washer either of wood or leather (*c*, *c*, Pl. XII, *figs.* 1 to 9) or a cupped leather (*k*, *k*, *figs.* 10 to 15) fixed on the axle, and running in a circular groove in the box, attains the result, but inefficiently.

We have no intention of launching into a description, even summary, of these different types. On the other hand, for making a choice, there must be grounds, but these grounds are wanting. It will be sufficient for us to set forth on the one part, the conditions to be fulfilled, and on the other, the principle of the solutions which are recommended in the absence of fully established success, by some useful feature, by some judicious and novel idea.

The spindles of machines are always lubricated by oil. For the journals of waggons, either oil or grease is used. It is objected to the latter that it acts only when the axle begins to heat, and renders it fluid; whilst oil prevents all heating. In spite of that, the use of grease is still widely spread; the boxes are in that case simpler. Under considerable pressures, besides, grease often gives perhaps an advantage, which in part compensates for those drawbacks; less fluid, it is less easily squeezed out. If experience has not yet established the absolute, incontestable superiority of oil as regards resistance to traction, that superiority is at least very probable. According to MM. *Vuillemin*, *Guebhard* and *Dieudonné* (*) this is very decided, as we shall see further on. On the other hand, a series of very complete comparative experiments between the *Orleans* and *Lyons* trains the first with oil and the latter with grease, did not result in favour of the first. It all depends on the care taken in the manufacture of the grease; the composition of which should, besides, vary according to the season; but that rule sometimes fails in the case of carriages which make long journeys, nearly North and South; a carriage may easily, for example, find itself at Nice in summer, after having left Paris the evening before, in winter. Nothing is also more variable than the quality of the oils, often so adulterated; olive oil is the best, but colza, rape and palm oils are more used. The use of mineral

(*) *Résistance des trains.* Mémoirs of the *Société des Ingénieurs civils.* Paris, 1865.

oils is very extensive in Austria. In every case the choice depends naturally on the local conditions.

I have seen employed at *Vienna* (State Railway) for testing oils, an apparatus composed of a spindle, supported on two plummer-blocks, at the extremities of which are fixed, on one side, a wheel on which is wound a cord making ten turns, and carrying a weight; and on the other, a fly-wheel with a counter. Each bearing, dried with care, received a constant volume of oil measured exactly in a cup. The oils are classed according to the number of turns made by the spindle, under the action of the weight.

For the same oil, this number of turns decreases more or less with the time, according to its quality. Altogether, provided that the surface of the bearing is sufficient, it is hardly doubtful that oil is in general preferable to grease; and that the latter will disappear when a receptacle has been found in every respect satisfactory. Oil permits besides the suppression of the holes and grooves in the bearing and thus leave intact all the useful surface of the bearing on the journal. The use of oil has been for a long time very general in Germany, where it is applied not only to carriages, but also to waggons. If the pains-taking habits of the officials and the moderate amount of the traffic are favourable conditions in certain respects, the extent length of the journeys, and sometimes the very prolonged delays, often of the waggons, beyond their own lines, would appear on the other hand to be a serious difficulty. It is not at all so however. Accidents arising from axle-boxes being out of order or empty, are very rare. Oil is, besides, exclusively employed in the United States.

With grease, the reservoir is necessarily placed above the journal, on to which the grease runs down through holes made in the bottom of the reservoir, and in the bearing; and by the grooves cut in the latter it is enabled to spread over the surface of the journal. With oil, the reservoir may be either at the top or at the bottom. In the latter case it is therefore by capillary action that it reaches the journal. If the reservoir is above a cotton wick plunged therein and ending in the holes of the bearing siphons the oil down. If the reservoir is below, the height of the journal above the variable level of the oil is compensated for, either by a cushion pressed up by spiral springs, kept constantly soaked with oil, by means of a cotton, or by a roller, in some cases on a fixed axle and dipping into the oil, in others free and kept immersed in oil by the journal.

In the American, or *Paget* box (Pl. XII, *figs* 10 and 11), the intermediate

space between the lower reservoir and the journal is filled, as well as the whole box, with cotton-waste which is always charged with oil by capillary action.

The "Rhenish" railway having taken possession of several lines belonging to different companies has had six different types of boxes, and amongst them, the American one. Some difficulties have been met with, as to the most convenient degree of compression to give the cotton. Too tight, it forms at the top a sort of crust which intercepts the passage of the oil; too loose, it leaves the journal. Moreover the oil being replenished from the top, at A, the greaser cannot tell whether oil is wanted, nor how much. This box has been improved, by modifying the lower lid, which has a cup on it for the introduction of the oil. As besides, the cotton might stop up the opening, it is often placed on the bottom of a piece of sheet-iron *mn* (*fig.* 11) ribbed and with holes in it, which isolates the reservoir and gives a large surface for the cotton to take up by.

M. *Dietz*, formerly engineer of the Works at *Montigny-les-Metz* (Moselle), of the "Eastern" of France railway, has succeeded in doing away with all intermediate parts, and lets the journal itself, for a portion of its length run into the oil. A sort of half collar, *c* (Pl. XVI, *figs.* 19 to 22), pressed up by a spiral spring which rests on the lower lid of the box forms a stop and closes the reservoir on the side next to the wheel.

The oil drawn up by the bottom of the front part *mn*, of the journal, is spread over the whole length thereof by the bearing; what is in excess accumulates in the supplementary reservoir *r'* where it is taken up by the iron cup *g*, put on hot where the axle enlarges. A scraper ρ checks the oil brought round by centrifugal force towards the edge of the dish, and causes it to fall back to *k*. This is certainly an ingenious arrangement; the "Eastern" of France railway has applied it to a considerable extent, and not without success; not, however, sufficient to render the adoption of M. *Dietz's* box exclusive.

The state of the naves of the wheels run with these boxes, show that they throw out the oil a good deal.

The disc, which is only an accessory in M. *Dietz's* box, is the sole means of lubrication in that of M. *Piret* (Pl. XII, *fig.* 9), who modified it and put it at the other end of the journal; it becomes then a sort of sucking wheel *e'e'* which takes the liquid from the lower reservoir and empties it above, in the cavity E, from which it is spread over the journal, through holes.

M. *Delannoy's* box (Pl. XII, *figs.* 7, and 8) differs from the others by an essential feature. Instead of being formed of two parts, that is to say, of

the box proper, and a lower lid forming a reservoir, it is in one piece and slips on the axle. The suppression of the horizontal joint is of itself a real advantage; the closing at the back is analogous to that of ordinary axle boxes; it is a disc, D, D, bolted on to the box : a packing of hemp c, c, tightened up by bolts, closing the joint. Putting it on is done, besides, without any difficulty This box is working successfully on some lines, among others on the section from *Palancia to Astorga* of the "*North*" of Spain.

Boxes with two reservoirs, the one below with oil, the other above with oil or grease, are often employed. The first works under normal conditions, the second is a *stand-by*. If the lower reservoir becomes empty the cotton of the upper reservoir is put into the hole in the bearing. With grease above, this substitution can easily be made self-acting. It is sufficient for this purpose to furnish the holes with a plug which is fusible at a pretty low temperature. This plug may be either of fusible alloy, of sulphur, or formed of a mixture of ordinary soap and stearine. If the lower lubricator fails the plug melts and the lubrication takes place from above.

76. *Lubricating by water.* — The question of lubricating by water has been much raised at various times. The useful effect of water in reducing friction cannot be denied, but while some attribute this to a really lubricating action, others admit to be its action simply that of cooling. This opinion is perhaps too absolute. If the rubbing surfaces can be separated in a permanent manner by a thin film of water, the result would perhaps be as good if not better than with grease or oil; and the whole of the difficulty is, without doubt, to keep in under the considerable pressures separating film of such fluidity, and which does not adhere to metallic surfaces. The curious experiments made by M. *D. Girard* with a view to his sliding railway, at least renders that way of looking at the matter admissible. We know that by forcing water between the journals and their bearings, and thus effecting a perceptible separation of the surfaces, M. *Girard* succeeded in substituting for the slipping of metal on metal, the slipping of metal on water, and thus reduced the friction in an enormous proportion. As to lubrication by water without pressure, the endeavours made in that direction have succeeded but indifferently. In Belgium, and on the *Eastern* of France, this was tried with M. *Piret's* boxes.

Soapy-water, tried a long time ago on the railway from *Leipsig to Dresden*, is often employed in the United States.

77. *Combined lubrication.* — A Belgian, M. *Haeck* has proposed the use of grease and water simultaneously. He keeps to the double reservoir-box, the upper one containing grease, the lower one water, which a roller pressed up by spring against the journal and revolving therewith, brings up on it. The interposition of a thin film of water between the two layers of grease, adhering, the one to the journal, the other to the bearing, prevents, according to M. *Haeck* the decomposition of the grease, and reduces the expenditure thereof. Whatever may be the explanation, the trials seem to indicate that there is something real in the utility attributed to this combination of water with grease.

Imperfect lubrication is a matter often greatly exaggerated. It consists less in permanently defective state than in accidental derangements. The heating of boxes is rather a frequent cause of delays to trains, expresses particularly, and mostly on those lines where the ballast is too fine. They heat a great deal oftener, for example on that account, on certain sections of the line from *Paris to Lyons* by the Bourbonnais, than on the Burgundy line although the speed of the express is much greater on the latter. What fails is always the perfect closing of the boxes where the axle enters.

The expenditure of oil or grease usefully consumed for the actual lubrication is very small, but difficult to appreciate. When a box is taken off after a given journey, an oil box for example, having had put into it at the beginning a given quantity of oil, and which has not been filled afterwards, there is found mixed with the oil, metal, dust, etc. On the other hand oil has escaped. Weighing refers only gives the gross consumption which often varies according to the system, and the state in which the box is kept, according to the nature of the ballast, and not to the question of useful consumption. All the systems which keep the oil in the reservoir in a perpetual state of agitation, which dash it about, introduce moreover a special cause of loss; oil agitated thickens and becomes changed. It may be said, in general, that the best process of lubrication would be that which would fulfil two conditions; to reduce to a minimum both the coefficient of friction and loss of lubricating material. The wear of the bearings can serve indirectly, failing experiments on resistance, as a measure to the friction; so that in confining ourselves to the observation pure and simple of the boxes, we might look upon as the best, that which throws out the least oil, and the bearing of which shows the least wear, and in which the oil does not become changed.

§ X. — Bearings.

78. Bronze is the most used especially in France. Its ordinary composition is:

Copper	82
Tin	18

On the "Méditerranée" system, the bearings are rejected when their thickness is less than $0^{in},24$; and, after boring down, grooves are not cut in those the thickness of which is reduced at the middle to less than $0^{ft},03$.

The alloys more or less analogous to printing types and often rather complex, have given results differing very much. In Germany especially, a quantity of receipts are to be found in the workshops, none of which seem to possess any well verified advantages. The difficulty is especially, to obtain homogeneity. The double alloy, 85 lead and 15 tin seems to be too soft for present loads. Too great fusibility is also a frequent fault in the more complex antifriction metals. The "Northern" of France, which made at the outset a trial on a large scale, of *Grafton's* antifriction metal, met with great drawbacks. The metal crushed, filled the holes more or less completely and that stopped the lubrication. Thence continual heating of bearings. Sometimes even, the bearings completely melted, have been found in lumps at the bottom of the boxes. As a lining, in which shape it is also applied, for example to excentric clips, antifriction metal gives better results. The following is the composition of the alloy employed on the "Great Western":

Copper	22,2
Tin	66,7
Antimony	11,1
	100,0

The following composition has been pointed out to me by the engineers of the Roman lines as giving good results:

Tin	37,5
Antimony	25,0
Lead	37,5
	100,0

Aluminium bronze would answer, no doubt, but its price is as yet too high.

79. *Roller-boxes.* — Theoretically, it is easy to reduce and even do away with sliding friction. For that purpose, it is sufficient to convey the load of the box to the journal, either by means of rollers turning on axles of very small diameter, or by means of rollers taking the load not at the centre but at the circumference. In the first place the distance run by sliding friction is diminished; in the second the sliding is replaced by rolling only. Those contrivances may be in their place in carriages subjected only to slow movements and therefore not exposed to shocks. Such is the case with the vehicles mentioned in (I, 315). But in carriages and waggons subjected to pretty violent shocks, these too delicate appliances easily get out of order. The advantages sometimes attributed to them and which would amount, according to their partisans, to an enormous reduction in the effort of traction, are besides remarkably exaggerated; because to the friction of the journal is attributed much too great a share in the effort of traction, especially when the speed reaches 30 miles an hour.

Rollers turning on axles have been applied to a certain number of carriages on the "Northern" of France. They were two in number, and brought the load on the journal on each side of the vertical plane passing through the axis thereof. Their diameter was $0^{ft},52$ that is to say double that of the journal. The axles were in steel $0^{ft},10$ in diameter, turning in bearings contained in the box, necessarily very much widened at the top. This arrangement due to M. *Pomme* and which conveyed the load to them seemed satisfactory at first; but more lengthened experience being less favourable to it it was given up. In the arrangement which gets rid of sliding, the journal is surrounded with a ring of rollers which turns round it. These carrying rollers must not be close together, as there would be sliding at the points of contact; they ought either to be kept at a distance by a light frame, or separated by other rollers of smaller diameter so that they may not take any of the load, keeping apart the principal rollers, which give them a rotation in a contrary direction to their own.

The disadvantages which caused the preceding box to be given up, are more striking in this one; M. *Vidard* applied it to the two-storied carriage running on the "Eastern" of France (40), but the Company has withdrawn the rollers. At the outset, and at a very slow speed, and in moving about carriages and waggons by hand, a considerable reduction of tractive power was effected by these apparatuses; but it soon becomes the reverse, particularly at a high speed. Such was the result of one trial, among others, made on some waggons of the Eastern Counties.

The very exaggerated idea entertained of the extent of the friction at the journals led, on the line from *Bolton to Leigh*, to a very singular contrivance: that of waggons with *double wheels* (*). The body rested on two axles with small wheels placed in the interior of the frame, and themselves bearing on two axles with large wheels, outside. Guard-plates, necessarily without any play, kept these two rows of wheels and axles one on the other. Railway history offers few examples of such strange conceptions.

§ XII. — Guard Plates.

80. The guard plate is a sort of fork which catches hold of the axle-box; it is sometimes simple (f. f. Pl. VIII, *figs.* 1 and 2, and Pl. XIV, *fig.* 1), sometimes consolidated by two struts *c*, *c*, at a very open angle; sometimes welded (Pl. I, fig. 1), oftener rivetted, and always applied on the inside of the longitudinals, unless on some English railways. It was also placed, originally, on the outside, in the stock of the "Piedmontese State" railways. This arrangement subjects the journals to horizontal strains applied to their ends, and consequently in the most unfavourable circumstances, particularly under the action of the brakes when the wheel is not acted on by two blocks. It is besides inconvenient, and its drawbacks are not compensated for by any advantage; thus it is done away with in Italy, whenever a carriage or waggon goes in for thorough repair.

The guard-plate although applied on the inside of the longitudinal, sometimes takes the axle-box by the front end; this arrangement is necessitated when the frame is very wide relatively to the gauge; the spring is then placed, not under the longitudinal, but against its inside face, and takes the load by means of brackets. By this, lengthening the outside portions of the axle, and raising the body are avoided. The stock of the Norwegian railways, which are on a narrow gauge, is in this case. Brackets, P, P, (Pl. IX, *figs.* 6 and 7), bolted on the vertical and external faces of the longitudinals, under which they project, rest on the springs by their horizontal bearings *m*, *n*. For a long time the lower end of the two guard-plates of the same side were always joined by a long tie-rod (Pl. I, *fig.* 1, Pl. VIII, *figs.* 1 and 2); it was first a round rod, afterwards a **T** bar, more rigid; but now-a-days this is often dispensed with, as it is of no real use in maintaining

(*) *Wood.* Treatise on Railroads.

the distance between the axles. Considered as forming with the diagonal portions of the guard plate ending on the longitudinal, a frame of which the plates would be the struts, these rods are none the more efficient; working in compression, they are too long to oppose any sensible resistance to the deflection of the longitudinals. There are no grounds for them but in brake-waggons, with brake blocks hung from the body; they act then as tie-rods to help the guard-plates subjected to the thrust of the two blocks, placed between the wheels.

The two branches of the guard-plates which are always united at their lower ends by a small clip, ought to be low enough to prevent the clips striking against the axle-box, either when the waggon is empty, or from the oscillations of the springs.

The axle-boxes do not fit tight between the guard-plates. A slight play is always left, both end-ways and side-ways, to facilitate running through curves. We shall return to this point (174). But the small play crossways to the line, is also very useful on straight lines. It permits the elasticity of the bearing springs to act also in that direction, and to lessen the intensity of the shocks which are produced sometimes between the flanges of the wheels and the side of the head of the rail, as well as the strain which results therefrom on the axles (81, 2nd).

§ XIII. — Axles.

81. *Strains to which they are subjected.* — If an axle had only to resist the efforts which act on it in a state of rest, the rational determination of its profile would be easy. But the strains to which it is accidentally subjected, when in movement, and of which the precise measure is impossible, only allow its dimensions to be determined empirically.

The only point evident is the relative smallness of the diameter of the journal (8); but the ratio of this diameter to that of the body of the axle is not constant, and depends on the length of the journal. The latter ought not only to have a diameter sufficient to stand the load; it must also present to the bearing a carrying surface large enough, so that the lubrication is not interfered with by the expulsion of the lubricating material, the inevitable effect of an enhanced pressure on the unit of surface. From this point of view, the section of the journal by a plane passing through its axis, ought not to go below a certain limit, which experience alone can assign.

According to M. *von Waldegg*, the German railways which spend the least in lubrication are those whose journals have the largest sections.

This area A being given, the radius r results from the condition of the resistance to deflection and the length $l = \frac{A}{2r}$ follows.

The journal being loaded with a weight P uniformly distributed, we have:

$$\frac{EI}{\rho} = \frac{Pl}{2} = P\frac{A}{2r}, \qquad I = \frac{1}{4}\pi r^4, \qquad V = r.$$

whence, R being the maximum strain on the unit of cross section of the metal,

$$\frac{EV}{\rho} = \frac{2PA}{\pi r^4} = R; \quad \text{whence} \quad r = \sqrt[4]{\frac{2PA}{\pi R}}.$$

If instead of A it is l which is given we have the ordinary formula for journals :

$$r = \sqrt[3]{\frac{2Pl}{\pi R}}.$$

The maximum weight of a four wheeled waggon loaded is about 15 tons, 50. ("Méditerranée" system; coal waggon 15 tons, 36; timber waggon 15 tons, 54). The weight of the pair of wheels mounted reaches 1 ton, 60; but it is 1 ton, 50 on the average. The maximum load on a journal is thus 3 tons, 13, which for the actual section of $22^{\text{sq.in.}}$, ($3^{\text{in.}},34 \times 6^{\text{in.}},70$), corresponds to a pressure supposed to be uniformly distributed of 2 cwt, 78 on the sq. inch; and consequently a real pressure very much greater. This mean load of 3 tons, 13, which has no meaning but as a term of comparison, is superior by nearly 50 per cent, to the limit admitted some years since; there is nothing excessive in it, and it does not exclude good lubrication as long as the speed at the circumference of the journal is small, as in goods-trains.

Mr *D. K. Clark* admits that with a journal of about 3 ins, 15, in diameter, the zone of contact of the bearing is at least 2 inches in width; but in accepting the exactness of this value in a given case, it could not be accepted as general; any more than the uniformity of distribution of pressure in the zone of contact.

As to the body of the axle, its longitudinal profile varies; it is sometimes cylindrical, sometimes formed of two truncated cones, the small bases of which are joined by a cylindrical portion.

P being always the load on the journal, and consequently the reaction of the wheel on the axle, d the distance from the middle of the journal to the middle of the nave (Pl. XII, *fig.* 25), each half of the axle is solicited by a couple Pd. In the state of rest the axle is not subjected to other strains,

and we have at every cross section, I' being the moment of inertia of the cross section of the body, the relation $\frac{EI'}{\rho} = Pd$. If then I' is constant, that is to say, the body of the axle cylindrical of radius r', the elastic curve is circular, and the extreme fibres undergo throughout a strain

$$R = \frac{r' P d}{I'} = \frac{4 P d}{\pi r'^3};$$

while in the journal, solidly encased within the enlarged part of the axle, this strain is $R = \frac{r P l}{2 I} = \frac{2 P l}{\pi r^3}$; we have then for the equality of resistance in the journal and in the body of the axle,

$$\frac{r'}{r} = \frac{lI'}{2dI} = \sqrt[3]{\frac{2d}{l}}.$$

But in running, the body of the axle is subjected to further strains, but only in an intermittent manner and without counting the effort of traction transmitted either by the guard-plates, or by the springs :

1. To the efforts of torsion resulting from the fixity of the wheels on the axle. G being the coefficient of torsion, that is to say the coefficient of the elasticity of slipping (from $\frac{3}{8}$ E to $\frac{2}{5}$ E), α the angle of torsion per unit of length, F the effort for the unit of cross section on an element situated at the distance ρ from the axis, we have according the known laws of ordinary theory :

$$F = G\alpha\rho,$$

and M being the moment of torsion, I_1, the moment of inertia of the cross-section relatively to the axis perpendicular to its plane, or what is some times named the polar moment of inertia,

$$M = G\alpha I_1,$$

whence

$$F = \frac{M\rho}{I_1}; \quad \text{now} \quad I_1 = \frac{1}{2}\pi r'^4.$$

For the extreme fibres, $\rho = r'$, then $F = \frac{2M}{\pi r'^3}$.

If we suppose that one of the wheels slides by reason of its fixity with the other one, as takes place for example if that wheel is held by a brake acting on it only, the moment of torsion M is that of the friction, or f P h, f being the coefficient of friction, P the load, h the radius on which the wheel is running.

Let: $f = 0{,}3$ | P = 3 tns, 00, h = 1 ft, 64 | r' = 2 ins, 05 (the thickness at the middle is 4 ins, 13), we have F = 1 ton, 27 on the square inch of the extreme fibres of the minimum section of the body, a value which corresponds to the most unfavourable hypotheses and ought to be very rarely reached.

The moment of the forces of inertia of the wheel, upon which the brake acts only by means of the axle, comes in also at the outset of the action to increase the torsion.

2. To the efforts of flexion due to the horizontal reactions q, of the edge of the rails on the flanges.

These efforts act, on straight lines, in the vertical plane passing through the axis of the axle, and on curves, outside that plane. In the second case they tend to make the wheel twist round the radius running to the point of contact on the rail; but the strain which results therefrom may be looked upon as entirely destroyed by the guard-plates, without sensibly affecting the body of the axle, so that the efforts applied to the latter by the force q are nearly independent of its point of application. These efforts are :

1. A uniform compression $\frac{q}{\pi r'^2}$,

2. A strain on the extreme fibres $\frac{4qa}{\pi r'^3}$, a being the radius of the wheel measured at the neck of the flange.

The strains due to the load and to torsion are alone susceptible of exact estimation. As to the force q, evidently proportional, all things besides equal, to the load P, it is useless to dwell on the endeavours made to assign the limit which it may attain. In a straight line, on a well kept permanent way it is certainly very slight; it may be, on the contrary, very considerable if the road is bad, if the sleepers shake about, and if the speed is high. In curves, its intensity depends on the speed, on the radius, and the particular state of the vehicles, conditions which leave to the action of the rails on the flanges, a greater or less part in the deviation given to the vehicle. A slight longitudinal play in the axles, diminishes greatly the intensity of this pressure, especially for the front axles, on which it is principally exerted at the entrance into curves. The side wear of the crossing points and that of the flanges of the front wheels in vehicles not symmetrical, that is to say in the case of engines, as well as the tendency of the road to widen out on curves, (I, 207) are evident proofs of the pressure in question. But if it occurs very frequently on curves, and more or less often on straight lines, it then depends, on so many unknown and variable elements that its determination is impossible. It is of consequence to measure necessary forces, but this one is not such. Theoretically, it can disappear, what must then be endeavoured is less to estimate than to reduce it.

82. *Iron axles.* — The *Vereinbarungen* fix (art. 159), the following dimensions for axles " of very good iron : "

LOAD ON THE RAILS.	MAX. DIAM. at the nave.	DIAM. OF JOURNAL.	RATIO of length of journal to diam.
3,750 tns.	3 ins, 98	2 ins, 64	from 1,75 to 2,25
5,000 »	4 ins, 49	3 ins, 00	
6,500 »	5 ins, 00	3 ins, 25	

They limit themselves besides, for the body, to lay down the principle (same art.) that the diameter " ought to be in no part larger, than at the portion within the nave ". On some German railways, two different types have been adopted, one for carriages, and the other for waggons. On the Mecklemburg railways for example, D being the diameter of the portion where the wheel is keyed on, δ and λ, the diameter and the length of the journal, they make :

For passengers.............................. $\begin{cases} \delta = 0{,}67\ D \\ \lambda = 1{,}33\ D \end{cases}$

And for goods.............................. $\begin{cases} \delta = 0{,}75\ D \\ \lambda = 1{,}22\ D \end{cases}$

The greatest diameter and the least length of goods-journals, are in proportion to the greatest load, and the smallest velocity of rotation.

The dimensions recently adopted on the *Paris and Méditerranée*, are the following : *body of the axle*, two curved conical portions of 0 ft, 98 in length, and bases of 5 ins, 12 and 4 ins, 13 in diameter joined by a cylindrical portion of 2 ft, 30 in length. The utility of this reduction in the thickness of the body is in no way proved. What is wanted is, that the diameter, where the wheel is keyed on, should be amply sufficient to avoid all chance of fracture at that part, where it would be concealed; but it would be simpler and equally as efficient to keep the diameter the same throughout. The rolling stock authorities of the "Méditerranée" line, have moreover admitted to me, that this curved shape of axle, has been adhered to more as a tradition, than from any advantage it possesses; while on the other hand it has no drawbacks.

Portion within the wheel. Cylindrical. Diameter 0 ft, 41, length 0 ft, 60. Keyway 0 in, 79 wide and 0 in, 12 deep.

Journals. Diameter: 3 ins, 35, length 6 ins, 70; distance from centre to centre 6 ft, 31 (outside distance between the tyres when the wheels are keyed on 4 ft, 47). Carriage and waggons axles are turned down when the jour-

nals have lost more than 6 per cent. of their original diameter, through wear and turning down.

Figs. 58 to 65, Pl. XII, show the types successively adopted on that great system of lines.

83. *Steel-axles.* — The use of cast-steel axles has made, so far, but little progress in France, excepting on the *Orléans* lines; where it was introduced as far back as 1856, by the late M. *Polonceau.* Engineers generally have more confidence in iron of good quality. The motives from which so great an impulse has been lately given to the use of *Bessemer* steel for rails, apply very little to axles, which are subjected to very different actions. Axles made of crucible cast-steel are greatly in favour in Germany: especially on some lines. The *Vereinbarungen* allow (art. 161) a load of 30 per cent greater on steel than on iron axles; all things of course being equal. The question of the degree of temper of steel axles has often been brought forward, especially in Prussia. If one were to go by trials made on small pieces, that operation should certainly notably improve the conditions of resistance of the axle: as we are assured by one of its advocates, M. *Werner*, but, for pieces of considerable size, such as those in question, tempering is a delicate operation, very uncertain in its results, even with the assistance of the reheat. Without being completely abandoned, the question is for the present put on one side, and in my opinion, it was prudent to give up the extension of an experiment which might have been attended with serious results. As to the tempering of the journals of iron axles, it has been often practised with advantage on the *Brunswick* line; where it was established that journals made of fine granular iron tempered, wear longer than soft steel; but the tempering often causes slight cracks, which at the end of some years become complete splits. This has led to the adoption of cast-steel for new vehicles. The Rhenish railway continues however to prefer fine granular iron with tempered journals, to cast-steel.

§ XIV. — Breakages of axles.

84. *Question as to the influence of the distance run, and the change of texture of the metal.* — Breakages of the axles of passenger carriages are rare enough; besides they are often harmless, the couplings being sufficient to keep the vehicles on the line. They are however, sometimes

the cause of carriages running off the line, and all the consequences resulting therefrom; sufficient endeavours therefore cannot be made to prevent them. These breakages are naturally more frequent with goods-stock, where the axles are more loaded and more strained, by the frequent passing through crossings and by the shocks they undergo, either when running, or in shunting operations.

The joint conveyance of passengers and goods in trains called mixed, is often a working necessity; it offers, besides, no danger at moderate speeds. But at high speeds the chances of an axle breaking increase, especially in goods-stock, where the axles are more loaded, and sujected to more violent shocks on account of the less elasticity of the bearing springs, as well as of the drawing and buffing springs. It is prudent therefore to exclude these slow speed waggons, from all passenger-trains the speed of which attains a certain limit. This is what has been done on the "Méditerranée" system. The limit is fixed at 31 miles.

It is especially for axles, that the thesis of the molecular alteration of iron by wear has been persistently maintained. According to its partisans, it was a simple question of time, and the limitation of the distance run was the sole means of preventing an inevitable breakage the imminence of which no indication could show. Thus the order of the 15th November 1846 in a precautionary spirit justified by the opinion admitted at that period in the " messageries " service, prescribed that the distance run by axles should be registered accurately day by day. But that measure soon became neglected, by the very force of circumstances. Simple, so long as it was only a question of the trunk portions of the system, it became more and more difficult, and would be now almost impracticable. That condition however, still exists in the new " General Rules for working the Prussian railways ", of the 1st of July 1866 (*). In the terms of No 17 :

" The distance run by each waggon must be entered in a register. After a distance of 18,200 miles at the most, and in every case, after each period of two years at the most, the axles, the bearings, and the springs must be lifted and examined. "

If the carrying out of the second condition be really meant, the utility of the third, as regards the distance run, does not appear; if, on the contrary,

(*) Allgemeine Bestimmungen zur Sicherung des Betriebes auf den Preussischen Staats- und unter Staats- Verwaltung stehenden Privat-Eisenbahnen.

it is sufficient that one or the other of those conditions be fulfilled, they are far from being equivalent. The passenger-carriages run, in two years a distance variable, without doubt, from one line to another, but in all cases much more than 18,200 miles.

Very fortunately, experience has proved that these fears are chimerical. The thesis of the crystallisation of iron is in general abandoned, and M. *Khulmann* is to my knowledge, the only person who has sustained it of late years.

"Experience" he says (*Comptes rendus of the Academy of Sciences*, 1868, p. 585) "has proved that the crystallisation of rolled iron often gives rise to accidents. The frequent breakages of carriage-axles is the proof thereof. Locomotive axles which do not receive so many shocks from the inequality of the ground as the axles of carriages running on roads, crystallise less rapidly."

They do not crystallise at all, neither one nor the other. The pretended molecular alterations remarked in axles broken during running, only indicate one thing, a default of homogeneity in the material, and which was originally in it. If granular or even crystallised iron, has been found in fibrous pieces, these differences of texture were not the result of molecular action; they previously existed.

The gradual passage of iron to the crystallised state under the influence of high temperatures is incontestable: perhaps the texture may really become modified, also, under the action of repeated strains, which attain and pass beyond the limits of elasticity. That at least is the result of experiments made by a commission deputed by the the Austrian Government to study the question. That commission experimented on seven cranked locomotive-axles, solidly fastened at one end and subjected at the other by means of a cam-wheel to a great number of shocks and torsions and after a certain time the axle was broken, and the texture observed. One of these axles broke after having undergone 128 millions of shocks and torsions (this is the longest of the experiments) and was found to present perfectly defined crystals, the metal having completely lost the appearance of forged iron. But it may be affirmed at this date, that nothing similar takes place, because the sections are sufficient to keep the strains at a great enough distance from the limits of elasticity; thus far from being an object of suspicion, an axle which has run a long distance ought on the contrary, to inspire more confidence the longer that distance, because the very fact proves that it is exempt from faults of manufacture, which constitute a predisposition to fracture. To replace an axle is only warranted in two cases : the wearing down

of the journals, and the insufficience of the section, in consequence of an increase in the loads.

The axle must, it needs scarcely be said, be intact, that is to say, exempt from all commencement of fracture. It is rare that axles break all of a sudden, except in case of accident. Fractures ordinarily occur from the gradual extension of a crack more or less recent. When a crack exists, it is natural, that if the axle be kept in use, it will end in a total fracture. In this case the influence of the distance run is perfectly evident; but its effects have nothing in common with a change in the mode of molecular aggregation, and for an axle attacked by a commencement of fracture, the question is not to limit its running but immediately to replace it.

The true, the only guarantee of safety consists, then, not to limit the distance run which, once more, it is nearly impossible to verify under actual circumstances, but to seize at once on the slightest sign of fracture. The examiners are interested by a premium in seeking out and making known every indication of that sort; but in certain types of axle a difficulty is encountered, that is to say the tendency of fracture to take place within the nave.

85. *Cracks hidden by the nave.* — The couple which solicits the body of the axle, under the action of a pressure q of the rail on the flange, has for moment $q\ a$ (Pl. XII, *fig.* 25), but its leverage depends on the length of the portion within the nave; as has been shown on the subject of fish plates (I, 101), the resultant of the pressures of the nave on each of the two semicylindrical surfaces of that portion, passes to the third of its length K; the leverage of the couple with the moment $q\ a$, which acts immediately on the axle, is then $\frac{1}{3}$ K so that the force φ has for value $\varphi = \dfrac{3\ q\ a}{K}$. It is of consequence therefore, that the nave should be long enough; it is comprised between 0ft,50 and 0ft,65. To these reactions between the nave and the portion of the axle within it are added besides, those which arise from the insertion under very considerable pressure of the axle into the nave; 25 tons at least (the specification of the "Méditerranée" requires 30 to 35 tons), and the corresponding pressure per unit of surface is, like the preceding, the greater, the shorter the nave. There is, then near the internal face of the nave, a shearing effect which has to be added to the efforts due to bending. It is in effect in this plane or at a slight distance inside the nave that axles nearly always break.

In many types that local tendency to fracture was increased by the coni-

city of a certain length of the portion within the nave. Tightness was thus guaranteed in spite of a certain amount want of precision in the turning of the nave and axle; but there resulted also from it an increase of the pressures, which were concentrated principally on the conical part, and consequently an aggravation of the shearing effect. The suppression of this conical portion, combined of course with a sufficient section seems to offer complete security against the commencement of internal fracture, which it is especially important to avoid, because the most careful examination being unable to discover them they end of course in total fracture in service. If a little conicity were desired in the nave and on the axle it should be extended to the whole distance of the axle within the nave, and not localised towards the extremity. But the whole length cylindrical is preferable.

86. *Wheels with the nave prolonged.* — On the Bavarian State railway and that from *Frankfort* to *Hanau*, the endeavour has been less to prevent those internal fractures than to keep together the two pieces of the broken axles. For this purpose the nave of cast iron, is prolonged towards the inside, but with a diameter greater than that of the axle, and thus forms a socket round it, that clasps it, but only to a slight extent by the insertion of wooden wedges. The dangerous section of the axle is not displaced; it remains near the extremity and a little to the inside of the nave proper. If fracture takes place, the socket will keep the wheel on, and give the inspector time to take notice of the damage provided it be visible by certain signs, although actual separation has not taken place.

This idea of prolonging the nave, in order to make it a sort of fishing of the broken axle did not meet with success; it does little more than put off the difficulty, and that by an increase in the weight and the price of wheels.

87. *Wheels with double axle-boxes.* — The same thing may be said with greater reason, with respect to the expedient to which they were induced to have recourse in Saxony some sixteen or seventeen years ago, by the frequency of the fractures of axles. This consisted in loading each wheel by means of two springs and consequently two axle-boxes and of course two bearings. The wheel was thus loaded symmetrically as in a wheel -barrow, save the excess of diameter of the inside journal. According to comparative experiments made on the line from *Riesa* to *Chemnitz*, this arrangement increases by 25 per cent the resistance to traction. If even this estimate were exaggerated it is evident that they were astray; and that there was oniy one thing to do to increase the sections.

88. *Reduction of the load.* — As to a reduction of load while waiting for weak axles to be replaced which can only be done gradually; although without doubt a prudent measure it does not always produce what is expected. It would certainly be efficacious if the axles were sound, but an axle which has done work for a greater or less time under too heavy load often contains a commencement of fracture, and, in that case, a reduction of the load might delay, but not prevent complete fracture. It is thus that frequency of fractures has been found to persist in spite of reduction of load. When one series of axles gives rise to frequent accidents, whether owing to insufficient sections, to defective profile (returns too sharp), or to faulty manufacture, there is only one part to take: to withdraw them from traffic service, and utilise them if such can be done, for ballast waggons, for example.

89. *Examples: a. Eastern of France.* — Out of 27,635 axles with journals of 2ins,95 the *Eastern* of France line has had in nine years beginning at the 1st of January 1855, 266 fractures. They have been attributed to the defective nature of the iron, and a faulty profile. The iron was too soft, and the test paid too much attention to ductility. On the other hand, with the view of improving the lubrication by oil, the radius of the junction of the journal with the body of the axle and the neck, had been reduced from 0in,47 to 0in,20; such a sharp return is too much like a chisel-cut not to injure the metal. Perhaps also the ends of the bearings too vertical, sticking against the protecting extremities of the journals, produced under the relative transversal movements of the frame and the axles, violent shocks tending to break off the journal. In any case the softness of the iron was the main defect; for axles of the same type supplied by M. *de Dietrich* had much fewer breakages proportionally, than those from certain other sources.

90 *b. Union of German Railways.* — The Union of the German Railways, has collected some interesting particulars on the breakage of axles, some of which I shall give here.

Out of 214 breakages, noted in 1867, on the 22 most important lines (this figure 214 containing 12 engines, and 40 tender axles.

60	took place in	Dec., Jan., Feb.
49	» »	March, April, May.
36	» »	June, July, August.
69	» »	Sept^r, Oct^r, Nov^r.

Or 129 in winter, 85 in summer.

These figures do not at the same time, completely express the influence of the temperature, the different lines in this very extended group not being in this respect quite under similar conditions.

The mean duration of the working of the broken axles for each line, varied from one year to fifteen years and a half, and their mean distance run from 27,900 to 221,358 miles.

(These averages only apply to an inconsiderable portion, doubtless of the number of the broken axles, for which the returns were made).

The most considerable distance run, was by one of the broken axles on the Brunswick line : it was as high as 320,715 miles.

The 214 breakages were thus divided amongst the different categories of vehicles :

Locomotives	12
Tenders	40
Passenger-carriages	5
Luggage-vans	3
Post-office-vans	1
Covered goods	61
Open goods	92
	214

The causes of fracture, which it was possible to assign for 194 axles only, were :

For	100	excessive wear of the journals.
»	42	fault of form, notably returns too sharp.
»	23	bad quality of the iron, or defective manufacture of the axle.
«	5	excessive load.
»	4	deficient lubrication.
»	5	collisions.
»	15	divers accidents, running off the line, etc.
	194	

91 *c. Prussian Railways.* — The minister of Public Works at Berlin, publishes, annually under the title: *Nachrichten von den Preussischen Eisenbahnen,* very interesting statistical documents, a chapter of which is devoted to the breakage of axles. I extract from vol. XV, relating to the working of 1867, the following facts.

The rolling-stock of the system comprised at the end of 1867 :

		Vehicles.	Axles.	
1. Passenger-carriages	with 8 wheels..	11	44	9,115
	» 6 wheels..	2,291	6,873	
	» 4 wheels..	1,099	2,198	

			Vehicles.	Axles.	
2. Goods-waggons....	»	8 wheels..	687	2,748	
	»	6 wheels..	4,443	13,329	108,091
	»	4 wheels..	46,007	92,014	
					117,206

Of which 66, or 0,056 per cent broke.

These 66 fractures are thus distributed :

1. Between the vehicles of the different categories :

1. Passenger-carriages	8 wheels	0	
	6 wheels	1	(end)=0,022 per cent of total end axles.
	4 wheels	2	=0,91 per cent.
2. Goods-waggons....	8 wheels	0	
	6 wheels	3	(end)=0,034 per cent of total end axles.
		2	middle=0,045 per cent.
	4 wheels	58	=0,064 per cent.
		66	

3. With reference to the nature of the metal :

		per cent	
Ordinary forged iron.............	1	0,019	34.494 miles.
Fine grained iron................	1	0,003	119.287 »
Rolled iron......................	5	0,042	86.861 »
Bündel's Patent................	13	0,074	121.884 »
Puddled steel....................	5	0,036	55.577 »
Cast steel, not tempered.........	41	0,097	48.820 »
	66		

It will be remarked that the distances run, which in general are small, are not to the advantage of cast-steel.

3. With reference to their position in the axles :

42 or 63,6 per cent took place in the nave.
18 » 27,3 » in the journals.
6 » 9,1 » in the body.

The great predominance of breakages in the inside, indicates something to be done to change the position of fractures which cannot be prevented; but at the same time the figure of 0,056 per cent shows that effectively the essential result, that is to say the extreme rarity of breakage, is obtained.

53 of the axles (80,3 per cent) showed partial fractures already old; 4 (6,1 per cent) showed fresh and clean fractures; 2 (3,0 per cent) had faults in the metal.

The appearance of the seven other fractures was not stated :

47. Of the axles (72,2 per cent) were under brakes.

23	of the fractures	(34,8 per cent)	took place	in winter.
14	»	(25,8 »)		in autumn.
17	»	(25,8 »)		in summer.
12	»	(21,2 »)		in spring.
66				

92. *Frequent relation between the origin of the fracture and the key-way.* The breakages, at the key-way, often present a peculiarity long observed, but which has never been explained in a satisfactory manner. The gradual progress of these fractures is frequently revealed (but not so generally as is believed) by the appearance of the surfaces, which enables the point where they commenced to be determined. Now it is shown thus, that the first point attacked corresponds diametrically to the key which completes the fastening on of the wheel. The initial point of rupalture, seems thus to avoid the key-way. In this observation was believed to be found a preventive remedy : all that was required was to increase the number of keys. Two and even three were applied; but the same result took place : that is to say, that with two keys, diametrically opposed, the fractures took place at the middle of the two semicircles on each side of that diameter. With three keys, the summits of the three segments between them were first attacked. In result, it is always the part nearest the key, or one of them, which is the last affected. But if the addition of a second or a third key modifies the appearance of the fracture, it has no effect on the fact of the breakage; it is probable indeed, that looking better into the matter, it will be found that the multiplicity of keys, which of course ought to weaken the axle, really increases the chances of breakage. What is certain, nothing is that can be gained from an observation to which many persons attached great importance.

Many engineers even object to the use of the key, and probably, not without reason. It is quite likely, now that wheels are put on with such considerable pressures, that in the case of wrought iron wheels it might be dispensed with (85).

93. *Hollow axles.* — The nature of the strains to which axles are subjected, that is to say, transverse flexion and torsion, naturally led to the tubular form. Hollow axles have been in fact tried in England. The *Piedmontese State* railway tried a certain number of them, but they have disappeared; the breakages were relatively frequent. Experiments were made

at the worskshops of the *Vienna* and *Raab* line, in 1854, to compare the resistance of hollow and solid axles, of equal externat dimensions. The weight of the second was greater by 37 per cent than that of the first. Under the monkey the hollow axles bent much less than the others, a fact which is evidently an anomaly. On the other hand they yielded more to torsion under the action of the moment, nearly the same for the two forms, corresponding to the limit of elasticity. It is useless to dwell on these experiments, in which the influence desired to be shown by them, that of the form, was confounded with the nature of the metal. In fact, the solid axles were from Styria, and the hollow ones from Birmingham.

Some comparative trials have also been made by M. *W. P. Marshall*, secretary of the Institution of *Mechanical Engineers*. The axle, placed on supports, 5 feet apart, were subjected to the blows of a cast-iron monkey 17 cwt, 32, falling through 17 ft, 75. The deflection was measured, the axle turned, subjected to a new blow, and so on to breaking. But these experiments were too few to be conclusive, in the face of such enormous discrepancies in the results. Thus one hollow axle broke at the fifth blow; while another only showed at the twenty-seventh, a tear of 0 ft, 12 long, and only broke at the twenty-ninth blow. One solid axle broke at the sixth blow. It was thus very inferior to the second hollow axle, but superior to the first.

Subjecting the axles placed vertically to the shock of the monkey, the journals broke cross-ways in the solid axles, and longitudinally in the others.

In fine, although the hollow form of axles is logical, and although their mode of manufacture (103) seems to assure a more solid and intimate compression of the material, as well as more perfect welding, their working at any rate, much more conclusive than any trials, seems to have condemned them beyond hope.

94. There may be mentioned here, as an exaggeration of this idea of a hollow axle, a type of wheels and axles. Of the axle proper, there remain only the journals and the places for keying on the wheels, ending on the inside by a screwed continuation which takes a large nut. For the body there is a hollow cylinder of large diameter fixed by a circular angle-plate rivetted to the wheels, which are thus necessarily formed of a full plate.

Starting from this, we naturally arrive at an arrangement which has equally only an interest of curiosity : the central cylindrical portion of the axles, the diameter of which is equal to that of the wheels, takes the load within it : sliding friction is thus almost completely eliminated, the frame

acting only as a guide to the turning portions and to take the couplings But this system, which makes the useful load participate in the movement of rotation of the wheels, requires no discussion.

95. *Journals in the form of a double cone.* — An other peculiarity, which has been combined with the tubular form of axle, deserves to be mentioned: the double cone form of the journal (Pl. X, *fig.* 23). Its object was to prevent the axle from taking, as a consequence of the wear of the bearing, too much side play. This comes in principle, to the inclined planes now much used to control the longitudinal play given to the axle, with the view of easing the passage through curves. But such an expedient is only called for in the case of engines. The application was however defective; it is not the journal which should be acted on; formed of two truncated cones joined by their smaller base, it was evidently wrong with respect to resistance. On the *Bristol and Exeter* line, where cylindrical and *biconical* journals were run at the same time, the later heated much oftener than the first.

96. *Influence of the movement of rotation of the axle.* — The rotation of the axle is not without influence on the molecular action due to the load only. In the fixed axles of ordinary carriages, the upper fibres are always compressed, the lower fibres always stretched under a constant load, and if no shock takes place, they assume positions of equilibrium, which they go beyond only at the moment of putting the load. In an axle which turns, the putting on of the load occurs at very closely repeated intervals, and with a change of direction; the action is as if the axle were fixed, and solicited at the journal by a force acting always in a plan normal to its axis, but passing more or less rapidly through every direction on this plane. The fibres subjected to the maximum molecular strain, at the instant of their passing into the vertical plane of the axis of the journal, are in traction or in compression, according as they are above or below. At the velocity of 65 feet a second, or 44 miles an hour, wheels having, like those of the "Méditerranée" a diameter of 3 ft, 05, make 6,85 or nearly seven turns a second, and even more if they are worn down; a fibre subjected to the maximum strain in one direction, is thus subjected at the end of the fourteenth of a second, to an equal and contrary effect, and the change in the direction of the strain, between the two positions corresponding to the maxima molecular tensions takes place at the end of the twenty-eighth part of a second.

The authorities of the *Lower Silesia and the Mark* line have been carrying out for some years, a series of experiments on the resistance of iron and steel,

particularly with reference to axles. M. *Wöhler*, carriage and waggon superintendent who directs these researches, has endeavoured te approximate as much as possible the conditions of the experiments to those of practice. I take some of the results out of the report published by the author (*).

The apparatus (Pl. XII, *fig.* 52) is composed of a shaft A, carried on bearings, and having keyed on its middle a pulley P, which is turned by means of a steam engine. One of the ends of the shaft forms a dowel d, into which is let the piece to be tested, very true for a length l, having a portion of larger diameter which is fixe into the dowel, either by heating the latter (a method afterwards given up), by screwing, or when axles themselves are operated on, by the hydraulic press. The free end of the testing piece is held by a ring fixed at the end of a spiral spring r, provided with a graduated scale. This screw receives a tension t, by means of the nut e, so as to determine in the extreme fibres of the section of fracture, that is to say in that placed at the origin of the portion of larger diameter, a given strain : $R. \frac{vtl}{I}$; the movement of rotation is started, and continued until fracture takes place : that is to say, for years if necessary.

At the same time that it is bent, at every turn, in every direction, the testing piece is subjected to slight torsion, owing to its friction against the ring.

For every different nature of metal, a certain tension is started with which ought, according to previous trials to determine the breakage of the piece, in a pretty short time; and to the other identical samples are applied decreasing loads, to which correspond increasing numbers of turns.

97.1. Iron. — 1. *Bars drawn out cold from waggon-axles of the* Phœnix *Works.*

NUMBERS of the Samples.	TENSION of the extreme fibres in the section of fracture tons on sq. in.	NUMBER OF TURNS up to the time of fracture.	OBSERVATIONS.
1	15,05	56.430	
2	14,10	99.000	
3	13,14	183.145	
4	12,20	479.490	
5	11,30	3.632.588	
6	10,30	4.917.992	
7	9,40	19.186.791	
8	8,44	(*)	(*) The number of turns reached 70 millions, without any sign of fracture: The piece may be therefore considered as capable of resisting indefinitely under these conditions.
9	7,50		

(*) *Erbkam's Zeitschrift für Bauwesen.* Year 1863, pp. 233 and following; and year 1866, p. 67.

2. *Entire axles.*

These two axles coming from the works of *Laurahütte*, belonged to the "Upper Silesia" line. They were fixed into the hydraulic press with a strong cast-iron dowel (pl. XII, *fig.* 51).

1	9,40	896.300	Fracture exactly at the theoretical section : flush with the nave.
2	9,40	4.571.500	Fracture at 3/8 in. within the nave. (This experiment lasted 1 1/2 year.)

The enormous inequality in the two numbers of turns, can only be accounted for by the differences which is at times found to exist between pieces out of the same lot. It is probable that the dowel which took axle No 2, was very slightly opened out so that it compressed the axle with less force in the plane of the external face of the nave.

3. *Influence of sudden changes of section.*

(Same iron as n° 1.)

The trial pieces presented, near the nave, a sudden enlargement H, R (Pl. XII, *fig.* 53) at a sharp angle.

Nr	Tons on sq. inch.	Nr of turns.
1	13,14	40.000
2	12,20	58.000
3	11,30	83.000
4	10,30	224.000
5	9,40	445.000
6	9,40	409.000
7	8,44	956.000
8	8,44	535.000
9	7,50	1.386.000
10	6,60	8.999.000

The comparison of tables 1 and 2 shows strikingly the well known influence of sharp angles, and the necessity of effecting, gradually, changes of section.

98. 2. Steel. — 1. *Steel from two axles delivered in* 1861 *by the Bochum works. Return between the cylindrical portion and the enlargement fixed into the dowel.*

Nr	Tons on sq. in.	Turns.	OBSERVATIONS.
1	19,75	41.000	
2	16,00	214.000	
3	15,05	176.000	
4	14,10	596.000	
5	14,10	286.000	
6	13,14	687.000	
7	12,20	1.955.000	This anomaly can be explained by the boring out having been carelessly done, so that a projection was left inside the dowel.
8	11,30	280.000	
9	11,30	21.261.000	
10	10,30	»	No fracture, after 24.589.000 turns. Experiment ended there.
	2. *Same Steel, with sharp angle between the two portions.*		
1	11,30	225.000	
2	10,30	335.000	
3	9,40	738.000	

These figures serve to show again, here, the enormous loss of strength caused by sudden changes of section.

99. If we compare the molecular tensions which have determined fracture after a number of turns about equal both for iron and steel, we have :

40.000 turns.	Iron	13,14	Ratio :: 1 : 1,50.
41.000 »	Steel	19,75	
224.000 »	Iron	10,30	Ratio :: 1 to 1,54.
214.000 »	Steel	16,00	

But this ratio ought to improve to the advantage of the steel in question, as its manufacture and its quality get better and better, while those of iron remain the same. In effect, the steel coming from the *Bochum* axles delivered in 1863, that is to say, two years later, gave the following results :

Nr	Tons on sq. in.	Turns.	OBSERVATIONS.
1	16,88	127.000	
2	16,00	342.000	
3	15,05	627.000	
4	14,10	2.845.000	Rupture not in the theoretical section, when the strain was 13tn,14, but in the enlargement flush with the nave where the strain was only 8,88.
5	13,14	3.558.700	
	12,20	(*)	(*) No fracture after 14.176.170 turns. Experiment stopped there.

With a molecular strain of 16 tons on the square inch, this steel stands 342,000 turns instead of 214,000; with 15 tons on the inch, 627,000, instead of 176,000; with 13,14 tons on the inch, 3 558,700 instead of 687,000; with 12,20 tons, a number of turns pretty much unlimited, 1,955,000.

Cast steel presents much oftener than iron, the anomaly from which however its homogeneity ought to render it exempt, that is to say, the occurrence of fracture in a section which is not that of the greatest strain on the fibre. The steel of Messrs *Firth* of Sheffield, generally behaves in this way; fracture takes place in the enlarged portion, flush with the nave. This fact is of frequent occurrence, although in a less degree, with steel from other sources, that of *Krupp* among the rest. The maximum strain in the real section of fracture is often only two thirds of the strain in the section of greatest fatigue. If this fact arose from the enlargement, although very pronounced, not compensating completely the influence of the pressures exerted by the nave, it ought be pretty nearly constant, and affect iron as well as steel.

In order to estimate the influence of the movement of rotation on the molecular strain corresponding to fracture, M. *Wöhler* has operated equally on fixed bars, subjected to a multiplication of flexions but always in the same direction; these experiments only affecting railway axles as a comparison, it will be useless to describe the apparatus employed; and it will suffice to briefly indicate the arrangement thereof. The bar is placed on two supports, suspended, one from a fixed point, the other from the short arm of a Roman balance, the long arm of which is attached to the rod of a spiral spring which measures the loads. The flexion of the bar is produced by a beam of variable length, set as may be required, jointed with an ovat hole to a crank keyed on to a shaft, to which the steam engine imparts an oscillatory motion. In consequence of the manner in which the crank and the beam are attached, the latter can only act by traction on the bar, which, between two flexions, is relieved from all load.

Fibrous iron, from axles delivered by the *Phœnix* works. Length between supports $5^{bt},64$. Bars $1^{in},28$ square.

Nr	Tons on sq. in.	Nr of flexions.	OBSERVATIONS.
1	25,84	169.000	
2	23,49	420.000	
3	21,14	481.000	
4	18,79	1.320.000	
5	17,00	4.035.000	
6	14,10	(*)	(*) 14 millions of flexions; no fracture. Experiment terminated there.

Comparing this table with No 1 relating to the same iron, the following connection has been determined between the number of flexions producing fracture, and the maximum corresponding tension, according as the piece turns or is fixed. As besides, in the first case, to each turn two flexions of same fibre correspond, the number of turns in this comparison must be doubled.

			TENSION tons in inches.
With turning...	112.860	flexions produced rupture with	15,05
Without » ...	169.000	»	25,84
With » ...	366.290	»	13,14
Without » ...	420.000	»	23,49

100. *Influence of shocks.* — The shaft carried a cam raising through a distance of 2ins,56, a hammer weighing 2lbs,93, placed above the dowel, which thus received a shock at every turn. Under these conditions the number of turns determining rupture was, with equality of tension brought upon the fibres by the spring, reduced perceptibly one-half. And the bars with easy returns without shocks, made about three times as many turns as those with angular returns and subjected to shocks.

101. Mr *Wöhler* deduces from these observations that a fibre subjected to alternate extension and compression, yields to a tension little over the half of that which it supports under external strains applied the same number of times, but which act on it always in the same direction. Which amounts to saying that the resistance should depend on the sum of the displacements of the molecules, on one side and the other of their position of equilibrium. A law which could only be applied to the conditions under which the experiments were made, conditions incompletely indicated in the report, for the velocities of rotation, particularly, are not given.

" .... This alteration of elasticity " says M. *Poncelet* (*Introduction à la Mécanique Industrielle*, 2nd edition, p. 295) on the subject of alternations of extension and compression sufficiently repeated "may very well arise from the alternations or oscillations in question, succeeding each other at intervals too short for the molecules to have, at each repetition, the time to come back to their primitive positions of equilibrium, which they would reach at the end of a suitable rest, so that they get far ther and farther away therefrom at the end of each oscillation. Facts can be brought forward on this subject, which are something surprising to those who have not reflected sufficiently on the slowness with which certain molecular movements are accomplished, notably those which produce the rotation or the relative displacement of molecules. "

It is a pity that the experiments of M. *Wöhler* cannot, from the want of the necessary elements, be discussed and compared from this point of view, of the succession more or less rapid of the strains acting either always in the same direction, or alternatively in one and in the other.

Another consequence quite in accordance with what is daily observed with respect to permanent ways (I, 20), is that the equality of the resistances of iron to extension and compression, is not so close as is ordinarily admitted. In the experiments on rotation, it is impossible to distinguish whether fracture takes place by extension or compression. But in the trials with fixed pieces, it is always at the lower part that fracture occurs. Iron resists compression better than extension; and if equality is generally admitted, it is that, in direct experiments, the uniform distribution of the strain over the whole section, which establishes itself in the case of extension, is difficult to realise in compression.

§ XV. — **Manufacture of axles.**

102. The specification of the French railways requires for the most part *charcoal* wrought-iron. This is in reality iron puddled from cast iron reduced from the ore by wood fuel. Sometimes at Mr M. *de Dietrichs*, for example, the refining is done with charcoal in a small furnace. The specification, of the " Paris and Méditerranée " system, no longer imposes the condition of the reduction of the ore by means of wood fuel, but the nature of the ore, although with a certain margin.

" The cast iron employed " will, it says, " be taken for the most part from mineral from " *Mokta-el-Hadid* (Algéria); in quality, it will be equivalent to the best old sort of " cast iron made with wood fuel. "

At *Saint-Chamond* (Loire) the wood reduced from *Clavière* (Berri) is puddled, mixed with similar cast-iron from Corsica. At *Fourchambault* (Nièvre) each rolled bar from one bloom gives six clean cut lengths of slabs. The most homogeneous metal is chosen. The pile, made up of eight slabs of $0,^{in}79 \times 4^{ins},72$ section, is heated, welded under a steam hammer, reheated and rolled. Each bar yields five slabs. Then commences the special work of the axle, work which includes five heats, and is done by the shingler and under the steam hammer.

The first heat draws it out.

The second gives the outline of one half of the axle.

The third finishes that half.

The fourth gives the outline of the other half.

The fifth finishes it.

The cast-iron comes from Berri. The iron of the axle is fine close-grained and somewhat steely. At the works of the " *Eure* ", at *Zône* (Belgium) the pile for the axle (Pl. XII, *fig.* 55) is of wrought iron puddled from grey cast-iron, mixed, the interior is fibrous, the external portion shown by the shading, is granular. The pile heated to redness is rolled. After being passed through seven grooves, it is reheated, and finished under the hammer. In Germany, axles are made of charcoal cast-iron. In England, cast-iron from coke is used, but the coke is very pure; they also use scrap and the turnings of tyres. The form of the slabs varies. Thus at the works of the late Mr *Ashbury* near *Manchester* the packet heated and welded by the shingling hammer is rolled into bars of the shape *b* (Pl. XII, *fig.* 54). The axle pile formed of four similar bars and of a square core of fibrous charcoal iron is packed up, heated, then rolled. Afterwards half the bar is heated, the other half remaining outside the furnace. The first is hammered into the rough outline of the axle, which is afterwards terminated in the lathe, by the turning of the journals and the spaces for the wheels only. The other half undergoes the same work, in its turn. The axle pile is sometimes formed of bars of a crescent shape, but that offers no advantage.

I will reproduce here the conditions of the new specification of the " Méditerranée " line, 1868 :

The puddled bars will be sorted with care into series of different qualities; the first series will include the best qualities of fibrous iron which alone will be employed for the manufacture of the wrought iron.

The piles for the wrought iron will be made of bars without flaw, each being the whole length of the pile. The piles will be rolled into bars.

The bars obtained by the first rolling will be submitted to a second rolling. For this, they will again be placed in piles composed of bars each the length of the pile, and rolled into slabs of the dimensions hereafter indicated.

The piles for round blocks will be formed of slabs twice rolled, obtained from the preceding operation.

They will have the form of a rectangular parallelopiped of $1^{ft},15$ to $1^{ft},31$ deep by 9 inches broad, and of the necessary length for two axles. The bars of which the piles will be formed, will be the length of the packet. The two covering slabs will be the total breadth of the pile (9 inches) and 0 in,98 in thickness. The interior slabs of the pile will have a thickness of 0 in, 79. They can be of two pieces as to breadth, the one of 3 ins, 54 the other of 5 ins, 51. These intermediate bars will be placed so as to break joint. These piles, very regular in shape, after having been thoroughly welded under the steam hammer, will be rolled into rounds of 5 ins, 90, to 6 ins, 30 in diameter, for the manufacture of the axles.

The rounds made use of must be thoroughly welded. Those which show signs of faulty welding, even at the ends must not be employed.

The rounds which have been passed, will receive at least three heats to finish off each axle; one to draw out the body, and one for each journal. For drawing out the body a hammer of from three to four tons should be used, but the journals must be forged by gentle blows from a hammer of 880 lbs at the most.

All the axles will be tempered at a dull red heat in a tightly closed furnace for twelve hours at least.

The axles will be turned for their whole length, with the exception of the double cylindrical portion and the two conical pieces between that and where the wheels go. The distance between the journals, the profile, and the diameter of one and a half to three the axles will be verified by the gauge and must be entirely conformable, without any allowance, to the drawing. The holes of the lathe points will be left at the two ends of the finished axle. They must be at least $0^{ft},06$ deep.

Tests. The inspector will select for testing, two axles out of each hundred sent in for inspection.

The axle to be tested will be placed on two supports at a distance apart of $4^{ft},60$, and will be subjected to the blows of a monkey weighing 8 cwt and falling from a height of $14^{ft},76$ on the axle, at the middle of the distance between the supports; the blows will be repeated until the axle has taken a set of $0^{ft},98$ on the distance between the supports of $4^{ft},60$. The axle will be afterwards reversed and straightened by means of similar blows. After that test it must present no crack, split, nor faulty weld, however small. The test by bending and straightening, here indicated must be repeated three times, without the axle showing any crack, split, or faulty welding of consequence. If the first axle does not resist the tests, it must be rejected, and the inspectors must choose two more axles, which they must put to the same test. If these two axles do not bear the test, the whole lot must be also rejected.

The " Northern " of France specifies analogous tests.

Three axles are tested out of every hundred.

The axle placed on supports at a distance of 4 ft, 92 is subjected to the blows of a monkey weighing 5 tons, and falling from a height of 11 ft, 48. The blows are to be repeated until the axle is bent to the extent of 0 ft, 82, and often being straightened by successive blows, must show no crack.

There are the results of an axle given by MM. *Perin* and *Gaudet:*

Bending.	Set	*Straightening.*	Return
1st blow............	$0^{ft},164$	1st blow............	$0^{ft},695$
2nd »	0 ,325	2nd »	0 ,590
3d »	0 ,469	3d »	0 ,475
4th »	0 ,592	4st »	0 ,370
5th »	0 ,695	5st »	0 ,295
6th »	0 ,816	6st »	0 ,193
		7st »	0 ,065
		8st »	0 ,013

It is easy to understand why more blows are required in restraightening than in bending the axle. The convex form of the solid renders it, in effect, more able to resist the blows; perhaps also its pre-existing curvature would come in to reduce the fall of the monkey.

103. *Hollow axles.* — One word on the manufacture of hollow axles; in spite of their abandonment, they present a certain interest in themselves. The packet (Pl. XII, *figs.* 56 and 54), the diameter of which exceeds by 50 per cent that of the axle, is first clamped, afterwards heated and welded at the ends, which permits the clamps to be taken off; it is then entirely reheated and passed into the rollers, between the grooves of which, is inserted an ovoidal core, screwed into the end of a horizontal rod. The pile so rolled on the core, is taken back and withdrawn by changing the direction of the rolls. It is thus passed two or three times into each of the reducing grooves, which are all provided with a correspondingly reduced core. On coming out of the rolls, the pile is rounded exactly by a stamper, and cut to length by the saw. The journals have then to be made. They are shaped after reheating the two ends of the bar, either by the shingler, after having of course had a core placed inside it, or by rolling between cylinders as long as the axle, which is taken not longways, but crossways.

§ XVI. — **Wheel.**

104. In spite of the advantages offered with reference to the effort of traction, by a large diameter of wheel, that diameter is smaller in railway carriages, than in the most part of ordinary vehicles. The reduction of diameter is the consequence of the position of the wheels under the body. It is indispensable that they should be light, so as to reduce, not only the dead-weight, but also the rigid mass interposed between the rail and the springs; they are generally from $2^{ft},95$ to $3^{ft},28$, on the mean diameter. On a few railways only, the " Great Western ", for example, the diameter of the wheels of passenger-carriages is more considerable, but they have then be let in under the seats, which is troublesome in the arrangement of the bodies.

A wheel is composed: 1st of the centre; 2nd of the tyre; 3rd sometimes of a separate inside tyre or rim (*faux-cercle*)

It may be in wrought iron, in cast iron, in steel or in two or more of these combined; or of metal and wood together.

The centre consists of: 1st the boss; 2nd the spokes, or a plate in one piece.

105. 1st *Wrought iron wheels with spokes.* — The spokes are solids loaded on end. From this point of view, they ought of course to swell out in the middle, but on the other hand, they have to stand the horizontal pressures of the rails on the flanges (81). They are thus also solids, immovably fixed in the boss, and strained by a weight applied normally at the other extremity. In that respect, their normal dimensions ought to increase from the free end to the boss. This increasing thickness is all that in practice is given to them, and it is only applied to forged spokes, and not to spokes formed of rolled bars, which of course are of uniform section. The length of the boss has, for minimum, the thickness of the spokes, but it is much greater, as has been seen (85), on the one hand, in order to spread over a sufficient surface the pressure necessary to ensure the axle being well driven on, on the other hand, to limit the reactions set up between the boss and the axle, through the pressures of the rails on the flanges.

For a long time, the centre of the wheel was formed of spokes of rolled iron, with a boss of cast iron, and this economical contrivance is still greatly used at present; forged wheels being dearer. The bars, curved hot, on mandrils of different shapes, enter by their two ends into the cast iron of the boss, run in from a ladlefull of at least twice its own mass. Notches made in the ends of the bars, give a hold between the wrought iron spokes and the cast-iron nave.

Cracks, rare however in the case of the boss, do not involve the rejection of the wheel. They are put right by clamping the boss outside of the wheel. The clamps put on hot, on spaces turned down to receive them are often put on first, before the wheel is keyed on: one being then put on each side. When the bars curved on mandrils do not form with their circular portions a complete rim, (Pl. IV, *figs.* 6 and 7), the collection of spokes is too compressible to take the tyre, which ought forcibly to compress the wheel. There must then be interposed between the spokes and the tyre, a continuous hoop *c*, *c*: this is the rim. This extra piece is less useful in the case of spokes forming of themselves a continuous rim (Pl. III, *figs.* 1 and 6, Pl. VII, *figs.* 1 and 2), however it is made use of sometimes in that case also, because it allows the wear of the tyre to be carried farther. A corner piece, besides, is always welded at the angle of every two adjoining spokes, to consolidate the rim.

The "Eastern" of France railway has even gone the length of instituting a comparison between the second type, which was its own, with the first, which had come down to it from the old *Ardennes* company; and they give the preference greatly to the one without inside tyre. A pair of wheels complete of that type weighs 18 cwt. On the "Méditerranée" system, where the diameter is

a little less (mean of $3^{ft},05$), the normal weight is 15 cwts, 5, with a margin of one per cent, over or under. According to practice, the pair of wheels under that margin is rejected; above that, they can be accepted, but the excess is not paid for. It is especially to reduce the weight, that cast iron bosses are now-a-days being replaced by forged ones. Each spoke is in that case thickened out, so as to form the corresponding part of the boss. The processes of manufacture differ.

1st In the oldest which is also the simplest, *Sharp's*, two series of pieces are stamped out; the ones *a*, *a*, in the form of T. (Pl. XII, *fig.* 31), comprising an arc of the circle, and the upper part of the spoke, the others *b*, *b*, including its lower part and the thickened out portion. They are welded two and two, at *m*, fitted together and tightened up in a hoop, and taken to the forge, where the centre is brought to a white heat; the welding together of the thickened out parts constituting the boss performs itself, as the expansion, only able to take place towards the centre, creates thereby a very considerable pressure in the angles. A ring round each of the faces, completes the boss. There remains also the rim to complete by welding with the hammer, wedges in the angles *c*, *c*, (*fig.* 32), and turning out.

2st A simple process is often adopted in England which I saw a long time ago, in operation in *Börsig's* shops at *Moabit*, near Berlin. The spokes *r*, *r*, with their ends thickened, are welded at right angles to a straight bar *b*, *b*, the length of which is half that of the tyre (Pl. XII, *fig.* 20). This rake like piece is taken to a circular swage, where the tyre is centered by the hammer (*fig.* 30). The wheel is thus two in halves, which are welded together first at the nave as in the preceding method, and afterwards at the tyre.

3rd It is simpler still to take for starting point a bar of convenient shape (*fig.* 28) which, bent over a mandril, forms as in wheels with a cast iron boss, a portion of the tyre and two spokes, and moreover, the corresponding portion of the boss. The welding of the boss is done as above.

106. MM. *Arbel* and *Deflassieux* of *Rive-de-Gier* (Loire), have greatly improved the manufacture of wrought iron wheels. Their process consists essentially in heating a packet composed of a tyre, spokes, two slabs taking on to the ends of those spokes, and which form the boss; the bosses are slightly longer, which gives the wheel still unshaped and without connection, a decided protuberance (*écuanteur*); it disappears under the steam-hammer, but ensuring, and that is its object, a very considerable pressure between the welding surfaces, and consequently, a thorough good welding. The packet is shaped out in a swage, under a powerful steam-hammer. These

able manufacturers have ingeniously surmounted all the difficulties of execution which this method presents, and which especially consist in bringing at the same time to the same temperature, all the parts of the packet, formed of elements of different thicknesses. We shall return particularly to this point, on the subject of locomotive-wheels, the manufacture of which naturally presents greater difficulties.

107. *Wheels in one piece, or with a disc.* Wheels with spokes are sometimes reproached with taking, in the long run, a polygonal shape, through the flattening of the tyre between the points of support presented to it by the spokes. This disadvantage only shows when the tyre has been worn down too far. But another objection to spokes is better grounded, it is they act like the blades of a fan in carriages going at a great speed, and lift up clouds of dust; they might also, which is more serious, throw up red hot cinders from the fireboxes of the locomotive, and so set fire to the train (64). These drawbacks have seemed serious enough on some lines to cause the engineers to have all the spoked wheels filled up with blocks of wood, or with sheet iron. On others, a complete disc, either single or double has been substituted for the spokes. The single disc ought, like the spokes, to be thicker towards the boss, so that the function $\frac{I}{V}$ may increase towards the extremity, where it is solidly fixed; for the two discs, that condition is fulfilled by their greater distance apart near the boss. It has often been tried also, to give the single disc a certain flexibility, along the radius to save the rail and the tyre; its section along a diameter is then curved throughout its whole length (Pl. XII, *fig.* 23), it can then bend slightly under strains of small amount, and act to a certain point as a spring. Disc wheels are pretty considerably in use on the *Orleans* line, on the *Eastern* of France, and on the *Northern* of France, and very commonly in Germany and England. The simple disc is the most used. In *Hoerde's* first wheels the fastening between the disc and the tyre was effected by means of a circular T iron rivetted to the first, and fixed to the second by bolts with tapered heads (Pl. X, *fig.* 20). The intermediate T iron was afterwards done away with, by welding on to the disc a circular ring *c*, *c*, forming an inner tyre or rim, and bolted like the preceding one to the tyre proper (*fig.* 19); it is to this type that the wheels made at the *Providence* works belong, and used in France. Later, the rim itself disappeared, and the wheel has been made of one single forging welded on a tyre either wrought iron or *Bessemer* steel (Pl. XII, *fig.* 19).

The double disc presents one advantage, already indicated. It constitutes with plates of equal but slight thickness, a hollow solid of equal resistance. This allows lightness to be combined with great transversal resistance. The arrangement, leads to a modification in the form of the tyre which has on its side surface a flange, to which the two discs are applied, and rivetted. Wheels of this kind were tried nearly twenty years ago, on the *Taunus* railway. This form of tyre has been, by the way, also applied to a single disc wheel, the disc being similarly rivetted on to the flange.

The two discs presuppose necessarily a boss, either in cast iron, or formed of two hollow pieces between which the discs are fastened by means of bolts.

Cast iron is employed by M. *Cabany* an able manufacturer of wheels at *Ghent* (Belgium); the iron plates enter within the boss, which is cast on them as on the mandrilled spokes. These plates, having at their circumference a rim r, r, which is applied to the tyre, are like the wheels of the *Taunus* rivetted to its central flange (Pl. X, *fig.* 18).

The "Great Western" and the "North London" have tried a wheel with a double disc invented by Mr *Smith* (Pl. XII, *fig.* 24). The two plates very tightly fastened to the boss, by screws v, v, grip at their rim, between their turned over edges, a flange with a shoulder n, n, forged in one piece with the tyre. The inventor attributes to these wheels the property of limiting the torsion of the axle, the connection between the disc and the tyre being only due to the friction set up by the tightening of the screws, so that the inequality of the running of the two wheels could be made up for by the slipping of the centre portion of the wheel on the tyre. This is evidently impossible; the edges of the disc not reaching to the inside surface of the tyre, the total friction which they exert on the central flange must greatly exceed the load for the wheel to keep centered. π being the total pressure exerted on each disc by the screwing up, P the load, we must then have $2f\pi > P$ or, for $f = \frac{1}{3}, \pi > \frac{3}{2}P$. While for slipping to take place between the disc and the tyre, and not between the tyre and the rail, we must have, l being the exterior radius of the discs, ρ the mean radius of the tyre and f' the coefficient of friction of the tyre on the rail: $2f\pi l < f' P \rho$, whence $\pi < \frac{P f' \rho}{2 f l}$, and with greater reason, $\pi < P$, seeing that ρ is smaller than l, and f' at the most equal to f, and smaller than f when the rails are wet.

It is clear that the pretended relative slipping would be quite as impos-

sible, if the discs, larger (and being then able to do with less tightening) were to be applied to the internal surface of the tyre, or again, if their exterior edges were to be let in, without play, into grooves made in the flange of the tyre.

108. *Cast iron wheels.* The use of cast iron wheels is very old. In mines it goes back a century. On the *Liverpool and Manchester* railway, compound wheels, wrought iron spokes, tyre and boss of cast iron, were employed for several years. The rim was cast in a chill, but frequent breakages resulted in, first, the application of a wrought iron tyre over the cast iron rim, and afterwards the complete abandonment of cast iron.

Since then it has made up for that abandonment elsewhere. Almost exclusively employed in the United States and in Canada, it has acted very well there. Those disc wheels which have open spaces round the nave are in one piece, including the tyre. With the rollingsurface hardened by casting in a chill-box they can under loads and speeds, less it is true than in Europe, but also on inferior roads, run more than 120,000 miles without being notably hollowed on the tyre. The load on each rail is ordinarily $3^{tns},3$. A pair of wheels which figured at the Exhibition of 1862, in *London*, was still in an efficient state after running 150,000 miles, under a post office van. Mr *W. Robinson* of the "Canadian Great Western" estimates their mean running at 155,000 miles. They rarely give way, in spite of the length and the severity of the winters, and the hardness of the deeply frozen road. They are regarded as safer than wrought iron, and it is for this motive and not for economy that the preference is given to them. These wheels cannot be turned down on the tyre. They do not turn out of the moulds with diameters always exactly to their normal figure of $2^{ft},72$, but the greatest difference does not exceed 0,12 of an inch, and they can easily be sorted in pairs, without appreciable difference. They wear very slowly, and also evenly, provided that the brakes act on them with moderation. Their diameter before they are thrown aside may have come down about half an inch. The quality of the cast iron, always from wood fuel, and the manufacture of the wheels, are the object of particular care. The works of *Ramapo* (New York State, near *Jersey-City*, on the *Erie* railway) employs hæmatites from *Richmond* (Massachussets) and from *Salisbury* (Connecticut). This cast-iron is very fine-grained, very dense, and very strong, especially after a second melting. After being taken out of the moulds, the wheels are plunged into pito, covered with sand, and they slowly cool down, during four days. They are then taken out and minutely examined; the

least entails fault their rejection. The perfectly sound wheels, are then put in pairs according to their diameters, the boss bored out and forced on the axle, by hydraulic pressure, under a pressure of twelve tons and a half only. They resist, it is said, a pressure of forty tons.

The wheels of *Ramapo* are much esteemed. The addition of cast iron from used up wheels, a step practised in most works, is prohibited. Wheels made from recasting old wheels with the addition of a certain proportion of new iron, must bear the stamp O. W. Some railway companies, to prevent this use of old wheels, which they consider to give inferior results, have taken to dealing with these themselves, working them up into bar iron.

It is asserted that those wheels, when they make long journeys, give a less total of miles, than those which run short distances. Admitting the correctness of this fact, it is difficult to believe that the longer continuance of the journey should have any effect, and it must be attributed without doubt to different conditions of load or of speed.

In Europe, the use of cast iron wheels has only extended to a part of Germany, particularly in Austria. However they have also been adopted on the line from *St. Petersburg to Moscow*. Agreeing in the opinion admitted on the other side of the Atlantic, as to the guarantees of safety which those wheels present, in the case of severe climates, engineers have had sent out to them, from America, cast iron of the first quality; the wheels $3^{ft},17$ in diameter are manufactured in Russia.

M. *Ganz* an able founder at Buda (Hungary), succeeded in getting rid of air bubbles and want of homogeneity and the state of tension which often makes people justly suspicious of cast-iron; others, notably M. *Gruson*, of *Buchau* (near *Magdeburg*) and in an inferior degree the Austrian *Staats-Bahn*, at its works at *Rechitza* (Banat) and the shops of *Esslingen* (Wurtemburg), have equally developed this manufacture in a striking manner. I shall describe in a few words the process as I saw it applied at M. *Ganz's*, whose death is a loss to that branch of industry (Pl. XII, *figs.* 26 and 27).

The wheel is a hollow solid thickened towards the middle. The tyre is cast in a chill-box, and the rest in sand. The core which fills the annular space *e*, *e*, having to be suspended, in a manner, to the middle of the mould, and to allow itself to be easily removed by means of three small circular openings *o*, made in one of the discs, is held up by a sort of body or frame in cast iron *k*, *k*, cast in place, and supported by three small slips of shed iron. After the casting is taken out, the core is destroyed by

means of a hooked rod inserted through the holes. The frame is easily broken and extracted bit by bit. The wheels once cleared out, the openings *o*, are stopped up to prevent stones getting in, which would render the wheel very noisy.

The fixing on of the axle is done without a key, excepting at *Rechitza* (*fig.* 13). Those wheels cannot however stand being forced on at a very great pressure, the axles therefore frequently work loose. The wheels in M. *Gruson's hartguss* can be forced on with less trouble. The German wheels generally answer well. At the end of 1867, the Austrian *Staat's bahn* had employed 19,000 of them, of which 16,000 were still running. In thirteen years, there only had been 14 breakages or 0,074 per cent. " None of the types in use on our line ", says M. *Schroeder* engineer of the *Staat's bahn*, " including the wheels with cast-steel tyres of the first quality have ever given so low a return ". He adds that the wheels from other sources are decidedly inferior to those of *Ganz*, by which they are being gradually replaced, and the manufacture of which has been greatly improved in its details, notably by bringing closer together the discs towards the rim with which they are united by a much larger radius than in the primitive type. Comparing *figs.* 12 to 16, and *fig.* 26, which represent respectively, the wheels of the *Staat's bahn* and those of *Ganz's* new model, gives an idea of the improvements introduced in the form of the second. The *Western* railway (*Vienna* to *Salzburg*), the *Northern* railway (Emperor *Ferdinand*), the *Berg*, and the *Mark* railways, have also several thousands of those wheels. The "South Austrian" has not adopted them, the heavy gradients of the most of those lines, requiring a frequent and prolonged action of the brakes, which these wheels are not well calculated for, the flat places resulting therefrom not being removable in the lathe.

On some lines, the "North East" of Switzerland, for example, the action of the lever brakes, which do not skid by simply lowering, is permitted, and does not seem to do any harm.

These wheels are economical. For the complete utilisation of a tyre, even in puddled or cast-steel, there are, in general, four turning operations, which, besides the expense of the operation and of carriage, keep the stock standing still. A good cast-iron wheel runs a more considerable distance without any expenditure.

But they do not inspire perfect confidence even in Germany. Excluded from goods-waggons with brakes, they also are without exception from passenger-carriages. The last *Technical Conference* of the *Union of German Railways* held at Munich, took up the question, and the conclusion it came

to was, that these wheels, when from known and tried manufacturers, may be used under goods-waggons without brakes, on condition that they are carefully inspected.

Although wrought-iron wheels are not exempt, either from risk of accident, caused especially by broken tyres, their double prohibition relative to passenger-carriages and to waggons with brakes is certainly most wise. They were even compelled, in France, to exclude from mixed trains, goods-waggons mounted on cast-iron wheels. When, some years ago the direct transport of cattle from Hungary to Paris became considerably developed, the Railway department to encourage that traffic, authorised the company of the "Eastern" of France, to admit, with passenger-trains, Austrian waggons with cast-iron wheels. But after two or three breakages, that permission was revoked. At present the "Eastern" of France receives from Germany a considerable number of waggons on cast-iron wheels. Those which were loaded with game, beer, and other merchandise by express, and which before were allowed to run in direct trains, are now exclusively confined to beer or cattle trains.

Cast-steel tends, however is, in this shape, as in others, to compete seriously both wrought and cast-iron.

109. *Cast-steel wheels.* These may be made in one piece like the preceding; or with a separate tyre. They are much in use in the North of Germany; at the works of *Bochum* (Prussia), a speciality of great importance has been made of this manufacture (Pl. XII, *fig.* 23). There they employ only crucible cast-steel. *Bessemer* steel, at least as yet, is only applied without being remelted in a crucible, to the manufacture of rails (I, 347). The casting of a metal, the temperature of which is higher and consequenly the shrinkage greater, than for cast-iron, presented special difficulties, which have been surmounted in the happiest manner by Mr *Mayer*, engineer of the works. It is not sufficient that the material of the mould be refractory enough; the mould must also follow the contraction of the metal, in order that the latter may be exempt from internal tensions. A careful tempering follows the taking out of the mould, and the wheel is completed by the lathe. Several wheels are cast at one time. At the Exhibition of 1867 an enormous batch of twenty-two wheels in the rough, weighing 10 tons, was much noticed. It had been cast vertically, according to the statement of the representatives of the works, a statement confirmed by the appearance of the mass. Top wheels would scarcely be taken as equal in value to bottom ones; however in the splendid mass in question, it was impossible to per-

ceive any difference of grain between the two end wheels, which had been partly turned, to show up the grain. This uniformity is due, doubtless, to the use of a very large mass of fluid metal.

These works guarantee a run of 55,000 miles, before turning down. According to the experience of the line from *Cologne to Minden*, that engagement is kept and gone beyond. Some wheels, even after a run of 72,000 miles and up to 94,000 miles, only show a wear of one eighth of an inch. It is admitted that these wheels can be turned down seven or eight times, and furnish thus a total distance run in eight or nine series, of 58,300 miles, or altogether, from 466,400 to 524,700 miles. On the *Minden* line, brakes are applied to them without scruple, unless on the portion with steep gradients, from *Cologne to Giessen.*

The annual distance rim by the passenger-carriages of this railway is, with express trains, 56,000 miles; with ordinary trains, 27,900 miles. The wheels would thus last from seven to eight years for the first, and double that period for the others.

Separate tyres (111) cannot be turned down more than six times at most. Their tension and their being separate, do not permit them the same amount of wear; they would break or come loose. Besides, when the tyre of a wheel all in one piece has reached the limit of wear, it is not on that account of no further service. Its flange is cut off, and it is then treated as the centre portion of an ordinary wheel; and a special tyre is applied to it. But the rim must not show too many air holes. The "Eastern" of France took for trial for that purpose from MM. *Petin* and *Gaudet*, a set of tender-wheels in cast-steel, with spokes. The tyres being worn out (and very rapidly) it was intended to replace them by wrought-iron tyres, but the old tyres were so full of air holes, that the intention was given up.

Sometimes, cast-steel disc wheels are objected to, on account of the sound they make in running. Their noise is perhaps somewhat different to that from wrought-iron wheels, but it is not greater. The manner in which they act under the working of the brakes, is a graver objection. Heated by the friction, and afterwards cooled, they may take, in winter, a temper hard enough to render them brittle, and thus brake while running. The fracture of a cast-steel wheel acted on by a brake was the cause of a passenger-train to be thrown off the line, near *Elberfeld*. Another wheel got heated by the continued application of a brake, the block of which had caught fire. Water was thrown on it, and the wheel undergoing a rapid partial cooling, gave way. Other wheels used under brakes, showing symptoms of fracture, were able to be withdrawn in time.

The steel ought to be soft, ductile, and suitably tempered. Breakages, and even simple cracks are then very rare, even under the action of brakes, provided that these are worked with care.

The engineer of the carriage-works of the *Minden* railway, looks upon, altogether, the *Bochum* wheels as the most solid, and most economical. It is not even necessary according to him, to exclude them from steep gradient sections, like those of *Giessen*, and it is sufficient to regulate the working of the brakes to avoid the drawbacks observed. The "Eastern" of France got ten pairs of *Bochum* wheels, which were placed under ten ton waggons. The trial started only in 1869, cannot, yet, give conclusive results. A pair of wheels fixed on the axle, of *Bochum* cast-steel, weighs 16 cwt,5, and coots £ 29 at the Works.

110. *Wheels with wooden discs.* — Filled up wheels, greatly used in England, are often done with wood. Less noisy than metal wheels, they save the tyres and the rails more. They seem to suit particularly in cold countries, their elasticity softens the hardness of the reactions of the road, when the ballast is frozen. Those of M. *Zethélius*, shown by the *figs.* 17 and 18, Pl. XII, do good service in Sweden, where metal wheels are however employed also.

Some persons still persist in attributing to wheels with wooden discs, the property of preventing the cristallisation of the axles, but in honouring them as the remedy, the evil is imagined. What there is true in this, is, that they lessen the intensity of the shocks transmitted to the axles and may thus prevent their breakage. But it is difficult to prevent the rotting of the covered portion of the woods, at the nave and at the tyre.

§ XVII. — Tyres.

111. *Section.* — If each carriage were intended specially for a certain line, its elements would of course be derived from the nature of that line. The section of the tyres would then vary from one line to the other. The conicity would have to be much more pronounced, and the flanges much thicker, as the curves were sharper and more numerous. But, now-a-days, this relation between the section of the tyre and the nature of line no longer exists, excepting on lines purely industrial, isolated, the rolling stock of which has been able to be made to them. On the great existing systems, which mostly consist of lines of the most varied nature, with the inter-

change of rolling-stock tending to take more considerable proportions daily, the approximate if not absolute uniformity, is in the nature of things. If even, at first sight, it seems that speed should be taken into account, and greater projection given to the flanges in vehicles running at high velocities, to keep them more securely on the rails, it is easy to recognise that uniformity in that projection, is preferable. In reality to all the flanges, is given the maximum projection allowable on a permanent way with chairs, leaving, of course, between the new flange and the side jaws of the chairs, sufficient latitude for the wearing of the tyre. This uniformity is more warranted, on the one hand, because slow-speed waggons might be run in a passenger-train and go, accidentally, at a great speed; and on the other hand, the vehicles of slow trains are submitted to special causes of running off the line, arising from the mode of coupling them, of the unequal heights of the buffers in case of very unequal loads, from sudden shocks in starting or stopping, and so on.

Altogether, carriage and waggon tyres are absolutely identical for each system of lines; and between one system and another, they only present slight differences, a reason for which would be difficult to find.

Now-a-days, and in the face of the increasing importance of the interchange of rolling stock between the great lines, complete uniformity would be simply reasonable. It will come to that, without doubt; only a type must be agreed on. Every one sticks to his own, and rightly, because he does not appreciate the advantages presented by the others. The advantage would be in fact unity.

Tyres generally present on the inside, and against the flange a return with a quadrant (Pl. XII, *figs.* 48 and 49). The object of that detail is not an insignificant economy of material, it has the advantage of diminishing somewhat the effect of the inequality in the thickness of the tyre, and to facilitate the manufacture a little.

Another more important peculiarity ought to be noticed : that the section of the tyre properly so called, is not entirely rectilinear. The conicity which is $\frac{1}{20}$ for the most part, is a great deal sharper towards the outside, where it is brought up to $\frac{1}{7}$. On the *Hanover* railways (*fig.* 49), the $\frac{1}{7}$ part occupies more than a third of the total width of the tyre, which seems too much. This shape has, as to its object, no relation to the broken section already quoted (I, 56) sometimes adopted for curves, and to which we shall return (175). It has in effect, only for object, to oppose a very injurious effect (I,49) of putting the tyre out of shape, that is to say the bearing of the wheel on the outside edge of the head of the rail. The getting out of shape of the

tyre, consists not only in the wearing down of the middle portion, but also in the bulging out of the metal towards the outside. From that double action, results a projecting sort of flange which may take on to the rail in the cross movements allowed by the play in the road, and the formation of which, is avoided or retarded by the chamfer made on the outside of the tyre.

112. — As we have seen, there is only on each of the French systems, one single type of wheels. But for the tyres of goods-waggons, a greater degree of wear is admitted than for those of passenger-carriages, especially at high speeds. On the "Eastern" of France a service order (10th. July 1866), recommends expressly to the officials of the carriage-department, only to employ when they have to replace wheels on carriages and vans bearing the inscription : *high speed*, wheels of which the tyres are at least 1in,38 in thickness. The wheels continue to run under waggons until the thickness becomes reduced to 0in,87.

On the *Paris and Méditerranée* system, all the tyres (locomotives, tenders, carriages, and waggons) have when new, the same mean thickness, 2ins,16. Those of the carriages and waggons are replaced as soon as their thickness comes below 0in,98. If a tyre has to be replaced while the tyre of the other wheel can still run, it is preferable to take off the latter also, when the wear of the new tyre has to be turned down too far for it to run therewith. The tyre so taken off is in that case put with another of the same thickness.

It is an easy operation to knock off a tyre. All that is required is, after having knocked out the rivets, the heads of which have been cut off, to heat the tyre for a certain length, thus it expands and a few blows with a hammer knock it off. This is just, on the large scale, the contrivance made use of to get out a stopper which has become too tight. A small special forge i employed on the Austrian *Staat's Bahn*, which greatly simplifies the operation.

On the "Upper Silesia" railway, iron tyres are worn down to 0in,79 which were when new 2ins,56 and even 1ins,68 in thickness, and steel tyres down to 0in,67 which were 2ins,18 in thickness. The *Vereinbarungen* admits that the wear may go down as far as a minimum thickness, at the middle, of 0in,75 for iron, and 0in,5 for steel.

113. The breakage of a tyre may sometimes result in very serious consequences. A tyre which breaks and comes off, may cause the carriage

to run off the line, rip up the flooring and seriously injure the passengers. The thinning of the flanges when it attains a certain limit, presents also dangers. If the tyres are narrow this may cause a train to run off the line, through the road-play becoming too great. It may also in passing facing points, cause the wheel to take the wrong line if the tongue rail is not perfectly close to the stock rail, and so bring about a running off the line, with breakage of couplings and so on.

This point has been the object of the following recommendations on the part of the "Eastern" of France company.

It happens pretty frequently, that waggons loaded for foreign lines are stopped at the frontier depôt, on account of the flanges of the tyres being too much worn. Not only results from this, the transshipment of the goods, the cost of which has naturally to be borne by the company, but further, the wear which arises from a difference in the diameters of the tyres of the same pair of wheels, and which may thin the flanges very rapidly, might cause trains to run off the line, especially when passing through points, the tongues of which are not always perfectly closed. To avoid this drawback, for the future the rolling-stock superintendent reminds those intrusted with the inspection of carriages and waggons, that every vehicle of the Eastern of France company, the flanges of the wheels of which are found decidedly worn, are to be immediately withdrawn from service, in order that all the defective wheels may be replaced, and particularly the inspectors of the stations where an interchange of stock takes place between different companies that they should stop the entrance on our system of lines, to foreign waggons which are found in the same conditions, and notice thereof should immediately be given to the agents of the traffic department.

February 1867.

114. *Putting tyres on.* — The means employed to put the tyre on, is taken from the practice of wheel-wrights. The interior diameter of the tyre is a little less than the exterior diameter of the rim. It could not then be put on cold. Expanded by heat it freely closes on the rim, which it afterwards strains tightly on cooling.

The elements of that operation should depend on the more or less ductile nature of the metal, on the tyre, and on the more or less rigid construction of the centre of the wheel. The *tightening*, that is to say the excess of diameter of the inside tyre over that of the tyre, both being at the ordinary temperature, is in practice $\frac{1}{1000}$.

Not tightened enough the tyre does not hold in spite of the connection effected by rivets or bolts. Too tight, it is submitted to a tension which might cause it to break.

This tension would be easy to calculate if the tyre were placed on a simple

ring without spokes. s being the amount of tightening, d the diameter of the tyre free, and consequently $d-s$ the inside diameter of the tyre, free and cold, these two diameters have, after putting on and cooling the tyre, the same value, which they reach, the one by extension, and the other by compression.

The diameter d of the rim has diminished by a quantity $\delta < s$. The diameter $d-s$ of the tyre has increased by $s-\delta$. A, A', being the cross sections of the tyre and of the rim, it may be admitted, because they are relatively small to the diameter, that the tension in the one, and the compression in the other are uniform throughout the whole of their section. The proportional elongation of the tyre is then $\frac{s-\delta}{d}$, and the proportional shortening of the rim $\frac{\delta}{d}$. Now the total effort of extension and compression being evidenly equal, we have :

$$AE\frac{s-\delta}{d}=A'E\frac{\delta}{d}, \quad \text{whence} \quad \delta=\frac{A}{A+A'}s.$$

The effort per unit of section is then:

in the tyre
$$R=E\frac{s-\delta}{d}=E\frac{s}{d}\frac{A'}{A+A'};$$

in the rim
$$R'=E\frac{\delta}{d}=E\frac{s}{d}\frac{A}{A+A'}.$$

If $A=3A'$, a ratio which often exists in wheels with forged rims,

$$R=\frac{1}{4}E\frac{s}{d}, \quad R'=\frac{1}{2}E\frac{s}{d},$$

and for
$$\frac{s}{d}=0{,}001, \quad R=\frac{1}{4000}E, \quad R'=\frac{1}{2000}E,$$

or for
$$E=28.400.000,$$

$$R=3^{\text{tns}},17, \quad R'=12^{\text{tns}},7.$$

per square inch.

But the inside tyre cannot contract without compressing the spokes, which by their reaction reduce this contraction. If to take a limit at once, we suppose that they render it incompressible, the diameter of the tyre would remain expanded by s. The proportional lengthening would then be $\frac{s}{d}$ and the molecular effort $E\frac{s}{d}$ or $12^{\text{ns}},7$ per square inch. It is there between these two extremes 3 tons, 17 and 12 tons, 7, that the real tension is, and it approximates the more to the second value, the greater the rigidity of the system of spokes.

On account of the immersion of the wheel in water, and by the rapid cooling of the tyre resulting therefrom, the tension is due not only to the tightening s, that is to say to the difference of the primitive diameters, but also to the tendency, more or less great, of the tyre to take, by the sole fact of this immersion, and if it were free, an inferior diameter to that which it had originally. This tendency is the more pronounced the more steely is the iron. The necessity has thus been felt of taking into account its nature, in fixing the amount of tightening. Formerly it was $0^{in},098$, and even $0^{in},118$ for ductile iron. Now-a-days it is comprised, for iron, between 0in,039 and 0in,047, for steel between 0in,028 and 0in,039. The less compressibility of the centres has also, like the more steely nature of the metal, its part in this reduction of the tightening.

This property of granular iron to contract by heating followed by rapid cooling, is sometimes taken advantage of for shrinking tyres which have worked loose. At the Works of *Epernay* (Eastern of France) for example, the tyre to be shrunk is heated and lowered flat ways, into a trough of cold water, into which it is plunged for the half of its breadth. The contraction effected by the cooling on the immersed portion acts on the part still hot, which is thus found to be definitively shrunk. After that first operation, the tyre is again heated, turned over and plunged again into cold water, for the half not yet immersed. After several successive heats and immersions, a tyre can thus be shrunk upwards of an inch.

115. *Tension due to centrifugal force.* — To the permanent tension due to the tightening, is added during running, that which is due to centrifugal force. This is easy to calculate approximately, although it only adds a slight increase. r being the mean radius of the tyre, e its thickness, we may take $erd\varphi$ for the volume of a small element subtending the angle $d\varphi$, and with unity for length (Pl. XII, *fig.* 44). The centrifugal force which solicits, at the velocity V, that element of mass $\frac{\delta}{g}\,erd\varphi$ (δ being the specific weight of the metal) is then :

$$\frac{\delta}{g} erd\varphi \frac{V^2}{r} = \frac{\delta e V^2}{g} d\varphi.$$

The component normal to the diameter, with which the radius meeting the element, makes the angle φ, is

$$\frac{\delta e V^2}{g} \sin \varphi d\varphi.$$

We have then

$$\frac{\delta e V^2}{g}\int_{\varphi=0}^{\varphi=\pi}\sin\varphi d\varphi = 2Re, \quad \text{or} \quad -\frac{\delta e V^2}{g}\cos\varphi + C = 2Re, \quad \text{or} \quad \frac{\delta V^2}{g} = R.$$

for

$$V = 65^{ft},61 \text{ (44,64 miles an hour)}; \ \delta = 7,70.$$

we have

$$\frac{7,70 \times \overline{65,61}^2}{32,18} = R = 310 \text{ tons} = 0^{tn}.20 \text{ per sq. in.}$$

This force has only a slight influence, even at high speeds.

116. *Fixing the tyre on the rim.*— Driving on is not sufficient to fasten the tyre, which gets more or less loose in work, and it should be endeavoured to keep it in its place, should it happen to break. It must therefore be fastened either by rivets, or bolts with conical heads let into the tyre (Pl. XII, *figs.* 41 and 49), or by screws with their heads inside, and entering into the tyre only $0^{ft},07$. Rivets and bolts passing through the whole thickness of the tyre are principally applied to wrought-iron blocked wheels, and the screws to forged wheels as well as to cast steel tyres.

The holes ought not to be drilled until after the tyre has been put on. Screws, which require a special tool to be used in the boring, done in that case from the inside, have the advantage of weakening the tyre much less. But, if they do render its fracture less likely, it is to be feared on the other hand, if fracture took place, that they would not be sufficient to prevent the tyre coming off, and the fragments separating.

For rivets, and for screw-bolts which are much less used, an iron is ordinarily specified of exactly the same nature as that of the tyre, in order to prevent them presenting, after more or less length of running, projecting points, if they were harder than the tyre, and hollows, if they were softer.

On the "Méditerranée" system, however, the absolute quality of the metal seems to be more important than the identity of sort, and the specifications prescribe the use of charcoal-iron rivets.

Sometimes they are placed instead of in the middle, a little on one side, to remove them from the portion of the tyre rim on; this lateral position is of course, compulsory in certain full disc wheels (Pl. X, *figs.* 19 and 20), unless in the way adopted at the *Providence* works, where the nuts of the bolts are let into notches managed in the discs.

Rivets and bolts do not weaken only the section of the tyre; their heads act as wedges which tend to split it parallel to the plane of the wheel. It is to avoid these lateral thrusts, that, on the *Berlin* to *Stettin*, and *Hanover*

lines, bolts with cylindrical heads are employed (*a*, *b*, *c*, *d*, pl. XII, *figs.* 42 and 49). But this form requires the holes to be made with the very greatest unity.

If the tightening, and consequently the friction, have become too small, the pressure of the rails on the flanges, submit the rivets or bolts to a shearing effort, from which they can be relieved, as was long done on the *Lyons* railway, by bringing upon the tyre a small external shoulder *e* (*fig.* 41), against which the rim is applied. This addition is little used; it is however useful, particularly if the edge of the rim has a good bearing against the shoulder.

In Germany, and especially in England, many attempts have been made to substitute some other mode of fastening for rivets and bolts and nuts, which are looked upon as weakening the tyres too much, and screws looked upon as insufficient.

In *Burke's* (Pl. XII, *fig.* 37) and *Dehnst's* (*fig.* 39) fastenings, the rim is trapezoidal in section, and its outside edge is let into a recess in the tyre, and the fastening in is completed, in the first, by the hammering down a sort of flange *e*, and in the second by addition of a ring *c*, forming a covering-piece screwed on to the tyre. In *Burke's* fastening, this flange *e* is beaten down all round. Sometimes a ring, slightly conical, is let into a groove in the tyre, the outside edge of which is only beaten over it, from place to place, and so fastens it in. The rolling stock of the "Mount-Cenis" temporary line, gives an example of this variation (*c*, *c*, Pl. XIII, *fig.* 10).

Fig. 38 represents an arrangement due to Mr *Beattie*, analogous to the first, and which requires, moreover, tyres of ductile iron, the metal having in this case to be beaten down on both sides.

Another mode tried also in England, is represented by *fig.* 40, which explains itself. But that fastening seems complicated, heavy, and subject to split off. It has however given satisfaction in Sweden, where M. *Zethélius* applies it to his wrought iron wheels, as well as to his wooden wheels (119). For the first (Pl. XII, *figs.* 20 and 21), it does not differ from the English mode of fastening, but in the suppression of the grooves inside the tyre, replaced by channels on the side and by two rings *c c*, the thickened circumference of which fits into these grooves.

M. *Daelen*, engineer of the *Hoerde* works, has contrived for disc-wheels the arrangement (*fig.* 43). The tyre carries on its inside face a flange *h* of a T form, analogous to that of Mr *Smith's* wheel (107). The disc with a corresponding profile, grasps sideways the shoulder of the tyre, and the latter once in its place, the fastening is completed by the addition of the

ring *a*, which, fixed to the disc by five or six screws *v v*, closes in the flange *h*.

This is a costly method; it requires a considerable amount of adjustment, and must be very accurate; it seems at first difficult to reconcile with putting on the tyre hot, the flange *n* introduced whilst hot, indeed by pressure, into the groove of the rim as it should be, after cooling, but slightly tight therein.

The suppression of rivets and bolts has been carried out also in disc wheels, with separate tyres. M. *Daelen*, who has studied with much effect, and not without success, all the details of construction of wheels, has contrived and applied the following arrangement: the tyre (Pl. X, *fig.* 21) carries two circular grooves *r*, *r*, between which is placed the rim, but the compression exerted by the tyre on the rim, may, as can be conceived, compensate for the shrinking of the flange, welded to the disc. Two rings *p p*, having a channel section, enter by one of their projections, into the grooves *r*, *r*, and rest by the other on the inside edge of the rim. By beating down the edges *m*, *n* of the rings *p*, *p*, the whole is rendered perfectly solid. M. *Daelen* exhibited at *Paris*, in 1867, an analogous mode (Pl. X, *fig.* 22), of suppressing the rings *p*, *p*, and only requiring one edge, that on the flange side, to be beaten down; but the section of the rim is rendered thereby very complicated.

117. *Steel Tyres.* — Wrought-iron tyres are sufficient with the actual loads on waggon-wheels. Steel, every day more and more used for locomotives, has been however, applied also for several years to waggons, and for this application as for the others cast-steel tends to replace more and more, puddled-steel. The Prussian Railway Department employs it exclusively for the tyres of passenger-carriages of the State railways.

According to M. *Krauss* the duration of steel tyres is five times that of wrought-iron tyres, but on the condition already specified on the subject of wheels made in one single piece, that those tyres should be, if not withdrawn from the action of brakes, at least treated in this respect with all necessary precautions; which amounts to saying that brakes must in consequence be increased in number, otherwise the wear is rapid and the alternations of considerable heating and then cooling, bring on fractures.

Abstraction made of the action of the brakes, steel-tyres harden, by the simple fact of running, to such a point that they cannot be touched by the turning tool. With puddled-steel, the hardening is only local, on ac-

count of the want of homogeneity of the material, which is unequally refined.

There is no agreement besides on one essential point: the degree of hardness of steel. Some look particularly to great hardness, for getting longer distances, but they thus expose themselves to the risk of fracture; others preoccupied above everything with safety, wish for a soft metal; but when they go too far in this respect, they get distances scarcely longer than from granular iron.

At the *Dortmund* works on the *Minden* railway they have given up, since 1862 the use of turning tools, which could not touch the hardened skin, even with a very slight set forward and moistening the surface with turpentine. Grinding is employed with success. It is somewhat difficult to get suitable stones. The best is the coarse grained sand stone of *Porta Wesphalica*. With their initial diameter of $2^{ft},00$ these stones make five hundred turns a minute. That speed increases as the stone wears down, it reaches to eight hundred turns, when the diameter is reduced to $1^{ft},50$. The bench takes the support of the points for the wheels and those of the stone, driven by a belt. These supports allow the stone to be brought forward or be put back, to be more or less inclined to the tyre according to its conicity. The surface to polish moves slowly under the stone; carriage wheels make nearly one turn a minute.

Dry or wet, the *Porta* sandstone gives a very fine dust mixed with particles of steel very injurious not only to the workmen near, but to the whole shop. These objectionable matters have been got rid of by means of a fan, the exhaust tube of which ends in a funnel, placed between the stone and the tyre, and which swallows up all the dust. The grind-stone is applied now-a-days to a great number of pieces in wrought-iron, as more economical than planing and shaping-machines. Many large workshops make use of this *sharpening* on a very large scale, and with much advantage. At *Swindon* (Great Western) it was introduced for wrought-iron tyres, by M. *D. Gooch's*, successor, M. *Armstrong*, and that example has been followed at the *Stratford* works, of the Great "Eastern."

118. *Compound tyres.* — The double function of a tyre which has on the one hand to strongly bind the wheels together, and on the other, to present to the reactions of the rails a very hard surface, leads naturally to the idea of a compound tyre, of which the inside and outside should by their nature correspond to these distinct functions. M. *Verdié* succeeded up to a certain point in carrying this idea out, by his process of casting

steel upon wrought-iron; but it happened, at times, that the first separated itself from the iron, and broke into fragments. Besides, cast steel possessing a resistance to traction not only equal, but even very superior to that of wrought-iron, the employment of the two metals combined can only be justified by reason of economy, and with the present prices of steel, that reason disappears; M. *Verdié* has therefore given that manufacture up.

119. *Means of fixing tyres on to wooden wheels.* — At the *Ashford* works (South Eastern), the process is in the first instance the same as in the case of metal wheels, that is to say, by driving on. Of course the tyre is very moderately heated and the whole is rapidly plunged into cold water, so as not to burn the wood.

At *Leeds*, at Messrs. *Lloyd Hoster's*, they put on the tyre in the same way as axles are keyed on, that is to say, cold, and by the hydraulic press. The tyre and wooden core are a little coned. The small base of the second is exactly equal to the large base of the first (Pl. XII, *fig.* 19).

The mode of fastening, still more indispensable when a slight tightening is employed, varies equally.

In Mr *Beattie's* wheel (*fig.* 22) the wooden disc is taken hold of at its circumference by two wrought-iron rings the exterior of which o is curved outwards and fits into a recess in the tyre. The other ring ω is tightened by eight keys c, c, let into a continuous groove in the tyre. The edge of the tyre is knocked down by the hammer on to the keys, which are thus fastened, and the disc solidly fixed to the tyre. It is clear that the outside ring o is placed first within the tyre, the other ω, is placed on the disc, and it is then that the tyre is forced on, as stated above. To take the tyre off, the keys are knocked down by a hammer until they can slip along to a part of the circular groove not beaten down, whence they can be easily taken out.

M. *Zéthélius* applies to wooden wheels the same method as to iron wheels (116), with rings c, c, provided with a projection penetrating into the groove of the tyre (*fig.* 17 and 18) as in the English fastening (*fig.* 40). The whole is tightened by bolts b, b, b.

Mr *Mansell* engineer of the works at *Ashford*, proceeds in precisely the same manner.

§ XVIII. — Manufacture of tyres.

120. 1. *Wrought-iron tyres.* — They are welded, or without weld (121). There is a real gain in avoiding welds, which are generally the weakest parts. Precise information as to their influence is however but small. Thus, the following may be cited, although it dates back several years.

From the 1st January to the 15th of March 1864, a period during which the cold was wery severe in the north of Germany, 376 breakages of tyres took place on the Prussian railways. For 250 only the circumstances have been stated:

87 took place at a rivet-hole;
65 » the weld;
33 » inside the metal;
65 were splits parallel to the plane of the wheel.
250

These figures prove that the endeavours made, either to fix the tyres solidly on without weakening them by rivets or bolts, or to avoid welding, are not without use.

a. Welded tyres. The tyre packets, rolled into straight bars, pass through ten grooves, four or five of which weld and draw out. The finishing grooves even when there are six, are ordinarily placed on the same pair; the length of the cylinders is not unreasonable. It is preferred however, sometimes to have two pairs, the one with four, and the other with two grooves; this method is a little dearer, but it allows when required the section of the tyres to be modified a little, at the same time keeping the large cylinders, and changing only the small ones.

Fig. 21, Pl. IV, taken from M. V. *Tunner* * represents the ten grooves of the rolls for tyres of the works of *Zeltweg* (Styria); the five last ones, all gearing are the finishing ones of the five first, three are mostly welding ones, and two for drawing out. The packet is turned: of 90° from 1 to 2, 2 to 3, and from 4 to 5, and 180° from 3 to 4.

A detail to note, in the shape of the finishing grooves 9 and 10, a shape studied with care, is the concavity of the inside face *m o n* of the bar. When that face is flat, it bulges outwards, when the tyre is circled, and

(*) Ueber die Walzenkaliberirung, etc., p. 69.

this bulging must be turned down; with a suitable concavity, on circling the bar a flat surface is obtained.

The inside face of the bar, at the same time that it swells out gets broader, so that the two side faces of the circled bar, are no longer parallel. That tendency may be got rid of by placing the last finishing groove upside down. The rolling face compressed by the upper cylinder, can then be kept broader than the inside face. They proceed in this way at some works, but the converse position is generally preferred, because the flange is shaped more exactly by the lower cylinder.

The tyres which have to be put on, to a full double disc (107); present on the inside face, a rib which serves to fix them to the centre. *Fig.* 20 represents according to M. V. *Tunner* the finishing grooves of the rolls of the *Piela* works (Silesia).

The bar is often jumped up at the two ends, to two chamfers, and welded by the addition of two triangular sets, which have to be of the same iron as the tyres themselves. M. *Pina* obtains with the steely irons of *Allevard* (Isère) a very solid welding, without previous jumping up, and without the addition of sets and with a great reduction of forge work. In this process, the welding between the two faces, normal to the bar, is due particularly to the pressure developed between these faces by the tendency of the tyre to expand by heat, and by the positive obstacle that a tie opposes to the increase of the diameter, perpendicular to the faces to be welded. Particular precautions are taken to prevent the metal from burning at the joint.

An analogous processis followed at *Fourchambault* (Nièvre) (Pl. XII, *fig.* 33 to 36). The tyre, circled on an ordinary roller mandril is taken by a long lever L, which carries two shoulders a, a; of which one forms the fixed nut of a pressure screw v. The tyre tightened in between the screw and the other shoulder, is carried to the forge, where the portions near the joint are covered with coal. The blast is put on, and when a white welding heat is reached, the screw is again tightened, so as to apply and strongly press against the other, the two faces of the weld M. It is forged by the hammer, and carried to the mould, which under the steam hammer, establishes the exact profile of the tyre; it is cleaned off by tool.

The tyre thus welded has not a rigorously circular form; the more so that the pressure of the screw has made it a little oval; it has to be blocked. It is reheated to a white red, taken hold of by a crane and placed on the sole plate A, (*fig.* 34) movable round its axis and carrying four rollers g, g, g, g, equidistant from each other, and from the centre. By means of adjusting

screws v, v, v, the three outside rollers G, G, G, are pressed against the tyre, the sole plate is then turned, and the outside face of the tyre brought into regular form.

The tyre still hot is placed afterwards on a cast-iron block P, P, (*fig.* 35) having exactly the inside diameter of the tyre, which in contracting, tightens on the cylindrical face of the block. The whole is plunged into a trough of cold water (*fig.* 36). This is thus a temporary driving on, with the tyre only very slightly tight.

The manufacture of tyres is sufficiently perfect now-a-days to enable them very often to be put on without previously turning out the inside face, in spite of the absolute precision required for the diameter. In Germany however they have gone back to turning out the wheels, which had been given up for a long time. It is better evidently, not to specify it, and to leave to those works which are able to do without it the benefit accruing from the perfection of their machinery.

The new specification of the *Méditerranée* states that :

The tyres will be in wrought-iron, of fine quality. The cast-iron employed will be taken, for the most part, from the mineral from *Mokta-el-Hadid;* in quality, they will be equivalent to the best old sort of cast-iron made with wood fuel; the puddling will be conducted with the necessary care and deliberation to give a well purified wrought-iron, of good quality. The tyres are to be perfectly welded in every part, free from cracks, flaws, scales, want of iron, or other fault.

They are besides, submitted to the following test :

" One tyre out of a hundred will be taken; this will be placed under a steam-bammer of 2 tons, falling from a height of 1 ft,64. It must not bend at each blow, more than 4 ins at the most, and only break after being flattened down 1 ft, 31.

Their quality is moreover verified direct, by tests of running, the details of the carrying out of which have been regulated by the following rules :

Out of each lot of a hundred tyres provided by the same supplier, *two* will be chosen, which will be set apart, and stamped with marks indicating in a very clear manner :

1. *The name of the supplier;*
2. *The year and month of the delivery;*
3. *The workshop receiving the tyres.*

Amongst the tyres from the same source chosen and marked as above, four or eight will be taken, which will be put with the necessary precautions on new or old wheel centres.

The mounted axles fitted with tyres to be tested, will receive two coats of white paint

but as that distinguishing color might rub off, a ring of iron will be rolled round the axles of those wheels towards the middle of their length, projecting enough for the wheels to be easily recognised.

Wheels bearing tyres to be tested will be placed exclusively at the two extremities of six wheeled luggage-vans without brakes, constructed lately for the carriage of parcels, and the traffic department will be requested to give a preference for trains running long distances, to those among them furnished with white wheels.

The series serving for the trials consists of one hundred luggage-vans marked DD 5001 to 5100, they can be easily recognised at once, because they have no shade and have sheet-iron on them vertically from top to bottom. The statistical department has received instructions to take exceptional care in noting the distances run by those vans from the 1st of January.

Placed in the conditions above defined and referring to former tests, the tyres ought to realise a total of 86,800 miles, in four periods.

During the first, the distance run must be..........................	26,800 miles.
After that run, the rolling surface of the tyres must not show at any point of the circumference a hollow of more than $0^{in},16$, when that degree of wear is reached those tyres will be turned up and then the wheels will be run again under vans of the same type as previously.	
The distances run in the second and third periods will be respectively 21,700 miles, or..	43,400 »
At the end of each of those two periods the hollow of the tyres must not be above 0m,16 at any point of the running surface.	
The scaling due to a superficial crusting-effect which the outside skin of tyres ordinarily presents must be regular all round.	
The distance run in the fourth and last period will be about 18,600 miles..	18,600 »
	86,800 miles.

After having accomplished this period the tyres will be considered as having served their time, and they will be replaced, if after having been turned down, they are less than 0^{in}, 98 in thickness.

The tests which have just been described will serve to determine the quality of the tyres provided by the different suppliers of the Company.

Progress of the operation. The tyres having been selected from the lots of the suppliers in the proportion of 2 per 100, as above explained, the following will be the manner of proceeding.

The inscription includes :

1. A particular number (each workshop having a different one);
2. The name of the supplier and his stamp;
3. The name of the workshops receiving the tyre; in general this number will indicate the workshop where the tyre is put on;
4. The month and year of the delivery by the supplier;
5. The nature of the tyre iron-steel-compound);

These inscriptions will be placed on one single line in the above order, and concentrically to the wheel, on the inside face of the tyre at three eighths of an inch from the edge.

The letters will be three eighths of an inch, the figures five eighths of an inch, and will be struck by a hammer, by means of stamps. This operation will be concentrated on three points.

Paris — *Oullins* — *Arles*, which will take the following numbers :

Paris	Nos	1 to 500
Oullins	Nos	501 to 1.000
Arles	Nos	1.001 to 1.500

Mounted axles, fitted with test tyres, will be distinguished by a ring of iron 1 in, 38, broad by 0 in, 59 thick, rolled round hot without welding, on the middle of the body of the axle. These mounted axles will be painted white.

As much as possible, two tyres from the same delivery will be chosen, and they will be put on the axle with care, and the document form No 2,320, will be established.

Return of the withdrawal and putting on of tyres, for axles with rings.

The part relative to the tyres put out of service will remain blank when the axle receives a ring and test tyres for the first time.

The workshop will besides keep a register form No 2,321, in which will be entered day by day the number of axles with rings put in working, or those of which the tyres have been replaced. This register, which will summarise for each axle the indications of the document form No 2,320, will present the continuation of the number of axles with rings done at the workshop, and, at their dates, the axles with rings from other supplies which have come to have their tyres changed. This will be a complete abstract of the work of putting on the tyres, done at a determined point, and a very useful document to consult, in case of damage arising to the inscriptions put on the tyres themselves.

Turning down of the tyres of axles with rings will be done exclusively in the workshops of *Paris*, *Oullins* and *Arles*.

A printed form nº 2,322, entitled *Official note of turning down tyres of axles with rings*, will verify the place and date of the operation. Observations will be entered as to damage and unusual wear of a nature to reduce the duration of the tyre, such as :

Flat places. — Bad welding. — Scales. — Exceptional wear of the flange.

The lifting of a waggon DD fitted with axles with rings should be done at the points most within reach of the shops charged with turning wheels down. To that effect, the running of waggons fitted with axles with rings or with white wheels, in the neighbourhood of those shops, should be followed with care, in order to have the necessary lifting done in good time.

For the same reason the foremen will refrain of small repairing shops or of sheds far off from lifting the said waggons or in case of necessity they should send to *Paris*, *Oullins* or *Arles*, the axle removed, and request another in exchange.

The lifting of a waggon DD, with a change of axle, will be verified by means of a register with counter foil, form nº 2,324, *Change of the axles waggons of DD*, on which will be entered the numbers of the axles withdrawn, and of the axles replaced on the date

of the day of the operation. This document will only be kept for waggons which have or receive axles with rings.

When an axle with rings has its tyres worn out, they must be replaced by other test tyres, and not by ordinary ones. In the same way, when a waggon DD is put on axles with rings, it must be kept so by substituting other tyres with rings when those in work require repair. This is necessary for simplifying as much as possible the work of the clerks intrusted with the verification of the distances.

The centralisation of all the operations relative to the running of trial axles, will be made in Paris; there must therefore be addressed to the principal engineer :

1. The notices of withdrawing and putting on axles with rings, form 2,320;
2. The notices of the turning down of tyres with rings, form 2,322.
3. The notices of change of the axles of waggons DD, form 2,324.
4. The distances run by the waggons DD (*this form is supplied from the head office*). Traffic Department form.

With these various returns, which should be sent in at the end of each month, a special account will be opened in a special register, form 2,323, of each test-tyre, and it will be kept up during every stage of its working, up to the day on which it has to be replaced.

Paris, November 2nd 1865.

The specification of the 20th December 1868 stipulates (No 12) that: " if the tested tyres are withdrawn from service (which takes place when their thickness is reduced to less than $0^{in},98$) before having accomplished the distance of 86,800 miles, the supplier has to pay the company for each hundred pairs of the lot tested, a fine calculated, at the rate of $1^{d},075$ per 1000 miles on the difference between the specified run of 86,800 miles and the distance effected by the tested axles.

121. *Tyres without weld.* — At MM. *Petin* and *Gaudet's*, at Saint-Chamond, the packet is composed: 1. of a plate in the shape of a parallelogram, rolled round and round close together, presenting consequently a helicoidal joint, and forming the cylindrical core; 2. of flat iron bars rolled round and round into a volute, and applied on the ends of the core; 3. of bars of granular iron, straight, trapezoidal in section, placed spirally between the two helicoidal flanges. This packet is heated, hammered, reheated, taken to the steam hammer, where the flange gets by degrees its form from moulds reheated and carried to the circular rolling mill, which gives it rapidly its definitive shape and diameter. The same process is applied equally to packets formed exclusively of bars rolled round each other in close spirals; this method, applied nearly twenty years ago by M. *Daelen*, completely does away with [the cross weld, but by multiplying the

welds parallel to the plane of the wheel; thus tyres so made, pretty often crack by the separation of the spirals. The compound packet of *Saint-Chamond* offers, then, more security in this respect. The introduction of cast steel diminishes, besides, the interest presented by weldless wrought-iron tyres.

The *Low Moor* works manufacture with their excellent iron, tyres of this kind, by means of discs hammered, and afterwards bored and rolled. This is moreover the classic process now-a-days, for cast-steel tyres.

122. *Cast-steel tyres.* — It seems natural at first, operating on molten matter, to take advantage of its fluidity to approximate to the definitive form, and only to have recourse to forging, for completing the profile. Thus, the process followed at first at *Sheffield* at *Bessemer's*, and at *Sandwiken* (Sweden) consisted essentially in casting an ingot, cut into discs, hammered, then rolled. But as it is only by the prolonged action of the hammer that the *Bessemer*-steel acquires its quality, a cast piece is now-a-days started with, the form of which bears often very little relation to that of the tyre. At *Sandwiken* it is a solid disc, to give a single tyre. At *Bessemer's* it is a large hollow ingot, cut into discs under the steam-hammer. Each disc is reheated and punched out. The ring thus obtained is widened out by the hammer on a mould which gives a section in the form of a trapezium, suitable to be transformed, by rolling into a section with a flange. The rolling mill, on *Galloway's* principle, finishes the tyre in a single operation. At *Crewe* it is a conical ingot which is heated, hammered on its two bases by *Ramsbottom's duplex* hammer, and so transformed into a disc of $1^{ft},84$ in diameter and $0^{ft},75$ in thickness. It is reheated, punched, heated anew and rolled.

At the *Atlas Works* at *Sheffield*, they try to leave as little possible to the rolling mill; the flange comes up under the hammer.

At *Glasgow*, on the contrary, Mr *Roway* employs a double rolling-mill, which greatly reduces the work of the hammer, and permits indeed of its suppression, but perhaps at the expense of quality.

The manufactures of crucible-steel endeavour naturally to compensate for the more elevated price of the material, by a form of casting which simplifies the further work. Messrs *Naylor Vickers* at *Sheffield*, cast the steel into rings, which are brought in to shape by a single turn of the rolling mill.

At *Bochum* they first cast the steel into a ring with a flange, and to a diameter of half of the finished diameter. At present they prefer casting a hollow cylinder, capable of giving from 20 to 30 tyres, sometimes with,

sometimes without flanges, and of a diameter equal only, to a third of that of the finished piece, the rings are separated and rolled. This method has the advantage of only requiring a single melting for the whole series, and thus reducing the waste.

M. *Krupp* alone, starts with a square ingot, giving from four to six tyres. This ingot is heated, flattened out, cut; each section carried to the steam-hammer in the form of (*fig.* 45, pl. XII), is punched cold with two holes *t*, *t* (*fig.* 46), and split from one to the other (*fig.* 47). The block is reheated, opened under the hammer by means of wedges, forged and rolled into a circular form.

The two establishments of *Bochum* and *Essen* seem to yield nearly equal products; the more complicated working out of the second, compensates perhaps, for the superiority of the material of the first.

The celebrated inventor of so many ingenious machines, Mr *Ramsbottom*, has recently invented a machine for widening out and shaping the rings for cast-steel tyres. The principle of this machine consists in forcing into the hollow of the ring, a conical mandril, grooved, revolving very rapidly, and which presses the ring against the rollers, which shape the conical tyre and the flange.

M. *Krupp* guarantees for his tyres a distance run proportional to the weight: for this law to be perfectly just, the tyres would have to lose in working, a constant fraction of their thickness and consequently of their weight; the distance run being besides, for an equal thickness, proportional to the diameter, and consequently also to the weight. This form of guarantee is the more favourable to the supplier the thicker the tyre is, because its rejection takes place when this thickness is reduced to a constant figure.

123. Testing by an acid is as useful for tyres as for rails (I, 322). Thin plates cut out of the tyre and having their faces polished, are left for twelve hours in dilute nitric acid. The resistance to the dissolving action of the acid, indicates exactly enough the resistance to wear, in such a way, that the test which puts in evidence, for the pieces of iron, the disposition of the layers by, may also prolonging it, give up to a certain point, an idea of the resistance of the steel, to mechanical actions. With plates taken from *Krupp's* tyres, the effect is only superficial at the end of twelve hours; while those which are taken from iron tyres, are at the end of the same time, almost entirely corroded by patches.

124. *Driving the wheels on to the axles.* — The hydraulic press is the means most used, but it is blamed for the uncertainty which exists as to

the pressure exerted. *Fig.* 50, pl. XII, represents the lever machine employed at *Ougrée*, near *Seraing* (Belgium). The toothed wheel B, fixed on to the axis of the pressure screw V, V, is worked by a pinion, the breadth of which is equal to the distance run by the axle E increased by the width of the wheel B. The cranked lever L′ and the straight lever L acted on by the first, and by the ties t, t, are forked. The weight P, which has to be raised so as to determine a pressure π, on the axle is fixed in each case by the specification. We have evidently : $P = \pi \frac{l d}{a h}$.

§ XIX. Couplings.

125. The relative velocities by which the carriages of a train are animated, at the times of starting and stopping, develop between them, actions of which the effects would often be destructive, if the shocks were not deadened by elastic appliances. For passenger carriages, their object indeed renders these appliances indispensable; but they are also so in the interest of the preservation of the stock. In the origin, it was tried on some small lines, to make them an exclusive privilege for first-class carriages; but it was soon recognised that that was a very poor economy. Now-a-days these appliances are put not only to carriages of all classes, but generally also to waggons. Only, the latter do not want appliances as perfect and as flexible as the former.

It is of consequence besides to remark that the interposition of an elastic system is not necessary in the same degree for the two directions of the reactions which the carriages exert one on the other. In passenger-carriages, springs of great flexibility are more necessary for buffing than for drawing, as the work absorbed may be much greater in the first case. The compressing together of the carriages of a train may thus attenuate, for the passengers, the consequences of a collision.

In waggons on the contrary, elasticity is, to a certain extent, a great deal more indispensable for drawing than for buffing. The latter can only cause damage to the frames, while with too rigid couplings, starting suddenly may cause the fracture of the couplings themselves, that is to say, an accident which occurring on a rising gradient is capable of bringing about the gravest consequences, if the portion separated from the train is not stopped in time, and runs backwards. The intensity of the actions at starting increases from the head to the tail of the train, because the mass in movement, that is to say, the mass giving the shock, and the speed, both increase.

Also the breakage of couplings, which by the way scarcely affects but the goods-trains but rarely occurs towards the head of the train (save of course in the case of a failure of the parts) but generally in the middle portion, or towards the tail. All fractures of couplings, unless it be due to a failure in the metal, involves, besides, a fine for the driver.

The regulation already quoted of the 1st of July 1868, of the working of the Prussian railways (art. 12), requires, however, that all the vehicles be provided not only with elastic appliances for drawing, but also elastic buffers *at the two ends.*

In passenger-carriages, the elastic appliances are almost always springs, analogous to those for bearing, that is to say plates one above the other; they only differ in form by a greater camber, because of the considerable work that they have to absorb in straightening, and the same springs transmit the two actions : drawing and buffing. Originally the two efforts were equally transmitted by the same bar. *Fig.* 44, Pl. XI, shows the first arrangement applied to the first carriages of the *Saint-Germain* and *Versailles* lines, *Right Bank.*

This system presents several disadvantages: 1. the position of the double spring, overhanging the extremity of the frame, increases its tendency to curve. It increases also the moment of inertia of the vehicle relatively to the vertical axis passing through its centre of gravity, and consequently its tendency to swing; 2. held together only by the middle of the cross beams, of the frame, the vehicles are too free to yield to the complex causes of this swinging, to which we shall return (126); 3. the frame participates altogether in the transmission of the efforts, either for drawing or buffing. Of these drawbacks, only the second existed in the first carriages of the *Ver saille* line *Left Bank* (Pl. XI, *fig.* 45). In this case the two springs were placed in the middle; the system of couplings formed one continuous elastic chain, subjected alone to the actions in the two directions : the frame being exempt therefrom.

Far preferable to the preceding one, this arrangement has disappeared in its turn, to give place to that which has been long adopted, almost generally. The two springs R, R (pl. X, *figs.* 2 and 3), placed in the middle of the frame, but back to back, are in length equal to the width between the longitudinals, and their ends rest on blocks τ, τ, bolted on to the inside faces thereof. The coupling-bar B is fixed to the buckle of the spring, which takes hold of the frame by the two blocks τ, τ. The transmission of the effort of traction by the frame thus reappears, but without disadvantage, that effort acting only on the longitudinals, and in the direction of their length.

It is easy to bring back to one's mind, in this respect the conditions of the old frame of the *Versailles* line, *Right Bank*. We have only to connect the two opposite springs by stirrups b, b, which complete the metallic connexion, and take wholly or partly on them the transmission, instead of the portions τ, τ, of the longitudinals. These stirrups are connected by special straps placed on the main plates, and nearly two thirds of their length, "Western" of France (pl. X, *fig.* 3).

As to shock, that is taken by the rods l, l, which traverse the blocks τ, τ, and end in blocks p, p, on the ends of the springs. It is conveyed, then, from one spring to the other by means of the single beam t subjected at its middle only, to an effort of compression.

It is evident from the double functions of the spring, that it is free, that is to say, that neither its middle nor its ends are fixed. It plays between the iron guides ω, ω, bolted on to the sides of the cross beams t, t, and these plates support it as well as guide it. The original camber of the spring is always less than the distance from the blocks p, p, to the middle cross beam t_1, so that the spring when in place has a certain initial camber. The application of auxiliary bars is especially suitable to the springs in question, as it diminishes their flexibility under great efforts.

126. *Coupling with double buffers in contact. Swinging.* It is easy to take advantage of this appliance, provided with distinct bars for shock and traction, in order to destroy or attenuate the swinging of the vehicles. Instead of running exactly according to the axis of the line the vehicles describe a serpentine line from one side to the other of that axis. The bearing springs, by their deflection, amplify these horizontal deviations, complicate them with vertical movements and the bodies of the carriages thus take a motion very annoying and fatiguing to passengers, and even dangerous, beyond a certain limit. If the road, in bad order, is up and down, if the sleepers are unpacked towards the ends, they oscillate round their centre; the vehicles are thrown alternatively from one rail to the other. The other causes are inherent to the vehicles themselves. Traction, oblique to the line, or not passing through the centre of gravity, a defective fitting on of the guard plates, and consequently a want of parallelism of the axles, develop this tendency of the vehicle to take a position oblique to the line, a tendency against which the conicity struggles, but by causing the vehicle take a serpentine course.

If a vehicle, affected by one or more of these causes, is comprised between two others which are exempt therefrom, a connection established transver-

sally to the line between these and the first, will interfere with its freedom; it will no longer be able to take a swinging movement, or at least it could only do so by taking with it the two other vehicles, and then the amplitude of this movement would be greatly reduced.

Moreover: when even several consecutive waggons are affected by the imperfections in question, the transverse connection established between them, remarkably improves their steadiness. The oscillations which they tend to make, which would in fact affect them if free, are neither concordant nor isochronous, so that if they are opposed to each other, they are mutually destroyed or attenuated.

Such is the effect of solidly attaching the carriages to each other, which ought to be carried out by very simple means, and applied with care to allow a train the necessary flexibility for running through curves. It is realised in a suitable way by making the buffers exert one on the other a certain pressure, at the same time that the coupling rods are tightened. The transverse connection between the consecutive vehicles, has then for value the friction developed by the buffers.

This notion is now common amongst persons who are in the habit of travelling on railways, we hear them frequently complain of their own accord at the stations, of the want of tightening up of the couplings of a carriage, in which they are being much shaken about.

This tightening is done by means of a screw, either simple or right and left-handed, with a link which joins the coupling-hooks of the two consecutive waggons (Pl. I, *fig.* 1; Pl. V, *fig.* 1; Pl. X, *fig.* 1). In coupling by means of a screw, the details of which are represented by Pl. IX, *figs.* 24, 25, 28, 29, and 32, the screw V works in a boss E, on the block B of one of the links, and the block B′ of the other acts only as a movable nut, but the screw with right and left hand threads, and consequently with two movable nuts is very generally preferred.

The porters ought to screw up the couplings tight, especially for express trains, and of course they can loosen them afterwards, if the train has to run along a section with sharp curves, which it only runs through, moreover, at a very slow speed, and where the swinging movement is, by that fact alone, greatly reduced.

It is evident that in running, and when the engine draws, the sum of the initial pressures between the right and left hand buffers is diminished by the whole effort of traction corresponding to the part of the train which comes after the buffers in question. In order to keep when running, a determined pressure between them, there must be developed then, by the buf-

fing spring, at the time of coupling, a pressure equal to the sum of that which ought to exist and the effort of traction. This initial pressure ought thus to increase from the tail to the head of the train.

We remark also that a train, formed and at rest, is composed of a series of systems, the elements of which are compressed, stretched, or bent, buffer rods, coupling bars, springs, supported by systems in freedom: the frames.

Coupling with double buffers which is nearly useless on lines of low speed, ought even to be rejected on those which present numerous and sharp curves. In that case it is suitable to return to the coupling consisting of a single bar, transmitting the efforts in the two directions. That is what M. *Phil*, does for the narrow gauge railways in Norway. *Figs.* 1 to 5 of Pl. IX represent the details of this coupling. The hook A catches on to the pin P, and is kept in its place by the guard chain *f;* the pin and the chain mutually fix each other by means of the double stud G; the key *e* serves only in the stations, when it is desired to prevent the hook from acting: it is then inserted into the hole *g*, under the hook; its jointed extremity hanging free, prevents it from getting out.

127. *Travel of the springs.* — The work of the springs ought to be limited in the two directions. It is so for traction by a stop H (Pl. X, *figs.* 2 and 3) keyed on to the draw rod, and which abuts against the cross beam *t*; for buffing, by the buffer, the inside face of which works up to the neck of the dead buffer F, which serves at the same time, to guide the rod, and for the buffers with long rods, which protect the projecting look-outs by a projection forged on to this rod. The limit of the play is often very different for drawing and for buffing. In the passenger-carriages and luggage-vans of the "Western" of France, for example, it is $0^{ft},72$ for the buffers and $0^{ft},21$ only for the draw-hook. This is even reduced to $0^{ft},11$ in carriages with an upper story, whilst the first, although diminished also, is still $0^{ft},04$. For drawing a slight travel is enough from the double point of view of the rolling stock and of the passengers; and the carriages with an upper story, especially with the special conditions of access to the upper story, ought to be withdrawn as much as possible from the movements produced by the reaction of the springs after stopping.

The reduction of the play of the draw-hook has another advantage: it allows the excess in the length of the guard-chains to be reduced (131).

On the "Western" of Switzerland the draw-hooks of the carriages, with springs coupled by stirrups like those of the "Western" of France (125) have a play of $0^{ft},60$; which seems excessive. The play of the buffers is $0^{ft},82$.

128. The buffers tightened in a suitable degree at starting separate while running, when the drawing effort acquires a considerable exceptional value, that is to say at starting, during getting up speed, and when the train is running up a gradient. The buffer rods go in, on the contrary when the engine slackens the speed of the head of the train, and when descending an incline. In observing the play of the buffers, from the inside of a coupé, approximate idea of the gradients can be formed.

By the coupling in contact, the train ought to be put in motion nearly at the same moment, from the head to the tail. With a very heavy train, in that case starting is more difficult than if the engine had only to overcome successively the inertia of the vehicles which compose it. Also the condition of coupling up tight is not obligatory for goods-trains, in which the elastic appliances have often only very reduced play. However, the shocks transmitted by the guard-plates to the axle, in the sudden changes of speed being doubtless not without influence on the breakages of axles, a service order (May 1867) of the "Méditerranée" Company says "to couple waggons in such a manner that the buffers are *as much as possible* in contact."

129. *Width between the buffers.* — At the period when the isolation and the small extent of the systems of lines allowed a rolling stock to be appropriated to the special conditions, on each of them, the width between the buffers was very small on lines which present a great many curves of small radius. Thus the Austrian railways have the buffers very near each other, $2^{ft},24$ from centre to centre (Pl. XIII, *fig.* 2). The "Northern" of Austria (*Emperor Ferdinand*) adopted later a still less width, $2^{ft},16$. But the carriages could not be coupled to those of lines which had adopted a greater width, except under the condition of applying double buffers. Now-a-days this complication has been rejected, the width between the buffers is uniform, $5^{ft},13$, and they make up for it by letting out the couplings when required.

In France, uniformity is only approximative, the width is: $5^{ft},58$ on the *Paris and Méditerranée* system; $5^{ft},62$ on the "Southern" of France railway; $5^{ft},64$, on the "Western" of France; etc.

130. *Form of the buffers.* — The buffers are either in iron fitted with a wooden block or of a disc entirely of iron; they present ordinarily one peculiarity. If they were flat, they would abut against one another by their edges on curves, and the pressure would tend to make their rods crooked. It is required that the pressures should be always applied towards the

centres of the discs, in spite of the relative inclination to their rods. Imitating the convexity of the rail (I, 49) it is so arranged that a convex buffer may be always against a flat one. It is sufficient in order that this condition may be always fulfilled, that the flat buffers and the convex ones correspond diagonally in each vehicle. In looking at a waggon endways there is always a flat buffer on the right and a convex one on the left (Pl. X, *figs.* 3 and 9).

This detail is not at the utmost of great importance on large lines; it has been recently given up on the "Eastern" of France system where all the buffers are kept flat. It is found simpler to have only one type. From another point of view, the buffers of two consecutive vehicles are not always of the same height because of the inequality either of the loads, the flexibility of the springs, or of the diameters of the wheels having tyres with different degrees of wear. If the convex buffer is the highest, the vehicle to which it belongs tends to lift. Running off the line caused by this difference of height is frequent enough; its effect is less with flat buffers, with which only friction tends to lift the carriages.

131. *Guard-chains.* —The screw-couplings are, as a measure of precaution, always double for each draw-hook, one only of them is hooked on, the other is in case the first one breaks.

But the screw-couplings are not the only fastenings between the carriages. The connection is completed by guard chains fixed to the frame on each side, level with the draw hooks, and hooked one into the other. (Pl. II, *figs.* 3 to 8; Pl. III, *figs.* 1, 4, 6, 9; Pl. V, *figs.* 3, 4, 8; Pl. VIII, *figs.* 5 and 6; Pl. IX, *figs.* 26, 27, 30, 31; Pl. X, *figs.* 1 to 5, 7 to 10).

These chains have not for object to help the principal coupling, but to be substituted therefore in case of any part giving way. But they fulfil that function imperfectly. When a train is formed, the chains must be more or less loose to allow for the play of the draw-springs. If through a fault in the metal, or starting too sharply, the coupling breaks before the chains come into action, they undergo a shock against which they rarely stand. If they both break, there is only half the harm done, unless the train were run backwards ; but if one only of them stands, the result is an oblique traction which might cause a vehicle to run off the line ;and in such circumstances the running off the line might be a great deal more serious than in the case of a vehicle kept on by intact couplings. In this respect a single chain placed along the axis would be better than the two side chains. This comes, it is true, nearly to the normal coupling, but without any disadvan-

tageous result. Some English railways, and those of Norway, (Pl. XV, *figs.* 16 and 20) have adopted this method. The Rhenish line has for a long time had only one chain; after its incorporation with the German railways, it had to adopt the two side chains, but the comparison is decidedly in favour of a single chain along the axis.

If two chains are thought necessaries, they should at least be placed close to the draw-hook. In putting them apart, as in the carriages of the "Western" of France, for example (Pl. X, *fig.* 3), at a distance of 3 ft,87 the obliquity of a vehicle drawn by one chain standing alone, becomes enhanced.

Guard-chains cause sometimes also accidents, always on account of their excess of length, which it is too often neglected to be adjusted in keeping with the play of the draw-hook (127). When they are not hooked on to another vehicle, that is to say, when they are at the back of a waggon at the tail of the train, they ought never to hang down free; but that recommendation, like many others, is not always attended to, and a hanging chain might while passing a crossing, catch hold with its hook of one of the parts of the line.

Accidents may even take place only it is true, by a conglomeration of circumstances happily very rare, without involving negligence or responsibility on the part of any one at all. Here is a recent example of this. The screw coupling of the eighth waggon of a mixed train of thirty-two vehicles running towards *Belfort* broke. The left guard chain gave way at the same time, kept hooked on to the following waggon, and dragged along the line. At *Bas-Evette* it caught between the check rail and the point of a crossing, the waggon to which it was attached ran off the rails, and continued to run on, drawn all the while by the right hand chain. After having broken several telegraph posts, in entering the *Belfort* station, it met with the cross rails of the transversing frame (I, 296) which threw it over on one side. The twenty-four vehicles which followed the broken coupling were thus drawn by a single chain, in spite of the shocks which were given to them by the waggon which was off the line, and the passengers, placed in the hind part of the train were conscious of nothing.

Altogether, there is something to be said both for and against guard-chains; they are still applied, but without any well grounded conviction of their utility, which is in fact very contestable, at least for passenger-stock. As to goods stock we may remark, so as not to return to this point, that their application is more warranted. It sometimes happens in shunting sharply (which cannot always be avoided with heavy trains) that a coupling-link of a waggon springs up and gets of the hook; and part of the train might

then run backwards*. Guard-chains, coming into action less suddenly because of a generally less travel off the drawing appliances, then prevent, if they stand, an accident, the consequence of which might be very serious. The Prussian regulation prescribes them without any exception (art. 2). At the Dresden meeting out of twenty-six companies who expressed their opinion on this point, seven only were for suppressing them ; the others decided to keep the chains, but recommended them to be increased from 0in,75 to 0in,86, and to employ a very ductile iron. A very wise recommendation without doubt, but to make use of a single chain would be much better. The chances of fracture are besides greatly reduced, by placing, between the cross beam and the nut of the pin which fixes them thereto, either an india-rubber washer *c* (Pl. X, *figs.* 3 and 7), or a steel spring with only a short travel (133) (*fig.* 10).

132. *Strength of the couplings. Position of passenger-carriages in mixed trains.* — On lines with stiff gradients especially, the couplings have to be very solid. Those of passenger-carriages are not, however, as strong, in general, as those of waggons: the effort of traction which they have to transmit being ordinarily much less. This is one of the motives for placing passenger-carriages at the end of goods-trains which carry passengers. Another motive is, that in stations the carriages stop at the platform instead of following the train through all the operations required by the goods service. The passengers who have not left their places are thus withdrawn from very disagreeable movements.

This position of passengers in the hind part of the train gives rise to an objection, the tail of a slow train (and those in question are such) being the part most exposed in case of a collision, seeing that it receives the shock from the engine of a fast train, if proper signals have not been made shown in time.

When slow speed waggons are added to passenger-trains they are placed, on the contrary, as much as possible in the hind part of the train, less with a view of avoiding a danger which the signals ought to prevent, than to give the passengers-carriages in the stations their normal positions, that is to say, alongside the platforms. But in that case, to prevent the passengers being subjected to the disagreeable shunting operations, only through-waggons must be attached to these trains. In this way without

(*) An occurrence of this kind took place on the 22nd of October 1868, at the station of *Saint-Jean-de-Maurienne*. But the guard-chains had been omitted to be hooked.

inconvenience complete loads can be arranged for the engines, on lines of small passenger traffic. This is what they do, for example, on the lines from *Paris* to *Montargis* and to *Corbeil.*

133. *Other drawing and buffing appliances for passenger-carriages.* — The appliances described higher up act suitably, but they are dear and heavy. It has been sought to substitute for them, either steel employed in other forms, or other elastic bodies, vulcanised india-rubber and even cork.

1. *Steel.* — In the original stock of the "Great Western", the large spring against the ends of which the buffer rods abutted, only served for buffing; the traction bar was formed (Pl. III, *fig.* 11) of two rods *t*, *t*, fixed to the hook, curving off and separating, 1ft,97 apart, and brought together again so as to be fixed on to one of the cross beams of the frame. In the space between them a steel plate *o*, *o*, was placed, rolled round in a circle and rivetted on to each of them at the point of contact. The elasticity of the system resulted from the tendency of the rods to straighten themselves and of the circle to flatten, under the effort of traction.

Coiled springs formed of a blade of a square or round section, rolled round a cylinder, have been frequently employed in England. They form, for example, the drawing and buffing appliances of the passenger-stock of the line from *Gloucester* to *Birmingham*. Now-a-days are preferred to them *Brown's* and *Baillie's* springs, formed of a bar of steel rolled round in a conical spiral, which at the limit of flattening becomes nearly a plane spiral. The section of the bar is an ellipse in the first, and in the second a long rectangle. These two springs are thus very analogous to the preceding ones. That of *Baillie's* is only in reality the coiled spring. (Pl. XI, *figs.* 1 to 9), with the modifications necessarily involved by the form of the blade, of thin broad section. As the pitch ought to be less than the breadth, the spirals lap over each other in a great measure (*figs.* 1 to 5), and roll round each other in cylinders of increasing diameters. The molecular effort in the extreme fibres being, all things equal besides, proportional to the radius, the condition of equal resistance fulfilled in the coiled spring, by a bar of constant section, requires for *Baillie's* spring, a plate of decreasing depth (*fig.* 2 to 4).

Brown's spring is greatly used in England, and *Baillie's* in Germany, where it is sometimes applied as a bearing spring, especially on certain engines where the usual plate springs could with difficulty be placed. In France it has only, so far, been made the object of some trials, the results

of which were but mediocre. After having been satisfied with *Brown's* spring applied to goods-waggons, the "Eastern" of France gave it up : the breakages were frequent, because of the coils riding one over the other. *Baillie's* spring, the coils of which are better guided, is preferable in this respect.

Of course under this form, drawing and buffing, have their distinct springs. For the first, a spring is applied against the inside face of each of the end cross beams, if the frame transmits the strain. A spring, single or double, *R*, *R*, is placed on the draw-bar, if it goes through the frame (Pl. XI, *figs.* 10 and 11). All the bars and the couplings form thus a continued chain, to which each vehicle is attached. It can be easily seen how the carriage is drawn along; if, for example, it is going from left to right, the effort transmitted by the rod T is applied by the key *c*, *c*, to the socket *m*, *m*, then to the two springs *R*, *R*, to the socket *m*, *m'*, and lastly to the block B, on which the socket rests. A groove made in the rod T permits it to play freely, without jamming the key *c*, and the limit of the effort which it is desired the spring should support, is fixed by the interval comprised between the socket *m*, and the block B. It is sufficient to cite this example of an arrangement which may vary in its details (Pl. X, *figs.* 9 and 10).

The continuity of the draw-bar, preferable to the two springs acting against the end cross beams, because it saves the stock, is however less used; it is but little applied except to goods-stock; the other is itself rarely used for carriages, for which the large springs with rows of plates, are generally employed.

As to buffer springs, they are placed ordinarily against the outside faces of the end cross beams, kept steady by dead buffers bolted on, taking the buffer heads on rods, which pass through the springs (Pl. XI, *figs.* 5 to 9). The frame participates thus entirely in the transmission of shocks, and has to be built accordingly; the cross diagonals, or if those are wanting, struts, stiffen the cross beams against the buffers.

M. *Œhme*, engineer of the Austrian State Railway, has simplified the arrangement of the overhanging buffing spring, in a manner which merits mention. The buffer has a side and under opening, through which the spring can be put in place or taken out, and constantly examined. The dead buffer to which flanges make up for its want of continuity, is furnished on the inside with a shoulder against which abuts a disc keyed on the rod, and which thus limits the compression of the springs.

The frequent fractures of cast-iron, dead buffer guides, have led to the substitution for them on several lines either of malleable cast-iron, or of

wrought-iron, the moulding and welding of which present no difficulties. They have besides the advantage of lightness, a consideration of some importance for overhanging pieces.

M. *Belleville* has recently introduced a steel spring (Pl. IX, *figs.* 13 to 14, 16 to 17) which seems to be recommended by some good qualities, and among others, the advantage of being composed, like india-rubber springs, of a series of independent elements, so that a breakage does not necessitate, as in the preceding types, the rejection of the whole. This spring has for element a blade of steel (*figs* 13 and 14) in the form of a very flat truncated cone without any bottom. Two plates applied one against the other, by their large bases form a couple; those couples are superposed in numbers variable according to the required travel (*figs.* 16 and 17).

These springs had been already tried several years ago by Mr *W. Bridges Adams*, who compared the complete washers with others split along a radius. The latter although naturally offering less resistance seemed to present some advantages; they have however both been abandoned.

In the United States they have returned to a coiled spring, but the bar of steel of circular section, is rolled spirally round a core of compressed wool. It is asserted that the action of this core greatly increases the resis tance of the system, and modifies the manner in which it behaves under increasing loads. Alone, the screw compresses according to the loads. With the core the compression increases less rapidly; the compound spring thus acts like an india-rubber one. The buffer does not press, in this case, against one large spring, wound round its rod, but against several springs of small diameter placed all round the rod. This arrangement is commencing to be applied in England.

2. *Vulcanised india-rubber.* The smallness of the coefficient of elasticity of india-rubber does not allow it to be worked, like steel, in flexion or torsion. Enormous sections would be required; it is by compression alone, that the change of form is produced. It is besides much too sensible to variations of temperature, which soften it or harden it, to be employed in its natural state; vulcanisation protects it from that influence, within sufficient limits. But this branch of industry has too often damaged the credit of its products by adulteration. The reduction in the price of steel, nearly at the same time as the appearance of india-rubber so prepared, helped also to hinder its use spreading, especially in France, where it is perhaps of a worse quality than elsewhere. It has been and is still in use in Germany and in England; on the Eastern lines, from *Cologne* to *Minden*, on the Rheinish railway, on the Bavarian and Brunswick State railways, it is de-

cidedly preferred to steel; however they employ but that of the best quality. It comes from America.

The element of the spring is always a round disc which alters in diameter and thickness under the pressure. In France these washers are cylindrical (Pl. IX, *figs.* 10 to 12); in Germany the cross section is sometimes rectilinear, sometimes concave or biconical (Pl. XI, *fig.* 13). In England, on the contrary, it is often thickened towards the middle. (*George Spencer's* spring (Pl. XI, *fig.* 46.)

Hollowing in the middle seems warranted, with regard to the proportions of the body compressed. A solid loaded on end ought on the contrary to be enlarged towards the middle, when it is long enough for flexion to intervene; but that is not the case with a thin washer. Experience proves moreover, that it can support without rupture, in a concave form, a much more considerable load than in a cylindrical form. It swells out, and if the pressure be increased, a ring of a triangular section *t*, *t*, (*fig.* 43) detaches itself, towards the middle of the height of the cylindrical disc. Hollowed, the disc becomes nearly cylindrical, and resists. Among the trials made to verify, at the time of delivery, the quality of the india-rubber, mechanical tests are still the most conclusive.

Its elasticity decreases rapidly as the pressure increases.

The discs are ordinarily separated by plates of iron, between which they widen out as they get thin, and which prevent them from overlapping each other. These plates carry near the rod, on which they are placed like washers a circular shoulder *e* (*fig.* 42), which keeps the india-rubber from touching the buffer-rod. These shoulders may if they project enough fulfil another function; as soon as they come into contact, all excess of pressure is taken by them, without affecting the india-rubber discs.

Thus arranged, the spring presents two drawbacks: on the one hand, the discs too near the shoulders, rest thereon; they interfere with and limit the expansion of the india-rubber towards the inside, so that it does not work uniformly; on the other hand the discs if too free, get out of place relatively to each other. In the new springs of the *Cologne* and *Minden* line (Pl. XI, *fig.* 41) the plate has a circular groove *c*; the projecting face is let into a hollow in the india-rubber disc, and the hollow face takes a projection made on the contiguous disc. The free lateral expansion of the india-rubber and the relative invariability of the position of the discs are thus ensured.

The shoulders on the discs have besides disappeared; limiting the efforts to which the india-rubber is subjected is then given up; a result which can

always at any rate be arrived at by means of a collar welded on the buffer-rod, and butting, at the limit of the travel, against the dead buffer.

In Mr *Spencer's* spring (*fig.* 46), the intermediate washers are biconical, with the large bases in the middle. This form is in accordance with that of the metal plates *d,d*, and their new functions. Instead of being interspaced between the india-rubber discs, plates or washers of malleable cast-iron of a T section are applied at their circumference. When the effort of compression is great enough for the india-rubber in changing form to fill the inside space of the ring, it rests thereon and ceases to spread out side-ways. The limit besides of the travel and of the effort corresponds to the contact of the edges of the plates. The absence of interposed discs, which this method besides, in no way excludes, is attended with some disadvantages, these are sometimes returned to.

134. *Sterne's pneumatic spring.* — The inventor of this spring has tried to carry out the very natural idea of the use of air as an elastic body. The spring is compound. The india-rubber plays a double part therein: 1. as a spring; 2. as forming the impermeable envelope in which the air is compressed. The system is composed of discs of the ordinary form, with interspaced plates, and of two plates forming the bottom of the air box; as the latter must not be traversed by the buffing or drawing rods, the spring is formed of two boxes placed one on each side of that rod.

The interposed plates ought in this case to act really as circular tie-rods, tying the elastic sides of the box together, and ought to be solidly attached to the latter. This sort of welding seems to be effected during the operation of the vulcanisation of the india-rubber. It is, by the way, applied to fifty carriages on the *Metropolitan* line, so that we shall very soon know what value to attach to it.

135. *Cork.* — It is tried in America, and, as would seem, with success, for goods waggons. It was at first feared that the cork would not resist. But it supports, they say, efforts which would damage india-rubber of equal section. After immersion in a mixture of water and treacle, which softens it and keeps it permanently damp, it is cut into discs of about 8 inches in diameter with a hole in the middle. Several discs are placed one over the other in a cast iron box; a wrought-iron lid with a similar hole in the centre is compressed by a hydraulic press, until the thickness of the cork is reduced to one half. A bolt is then inserted, the nut is put in its place, and tightened and the pressure withdrawn. In this state and held laterally

by the sides of the box, the spring can support a pressure of 10 tons without injury, and without ceasing to possess a very sufficient elasticity.

136. *Coupling peculiar to the North London.* — This made of coupling carriages *close up* (Pl. X, *fig.* 11), has particularly for object, to reduce the space between the carriages to a minimum, and consequently the length of the trains, for which the platforms are often insufficiently long. This has been attained : 1. by greatly reducing the travel of the buffers, which have india-rubber springs ; 2. by applying them only to one end of the frame, so that an elastic buffer E, is in contact with a dead buffer T; 3. by suppressing in great part, the drawing elasticity, for which only an india-rubber spring with small travel is provided.

The buffers of the luggage-vans on the end next the engine are alone, of the ordinary length, so that the engine can be easily coupled or uncoupled. The interval between two carriages is 0ft,88 instead of from 2ft,95 to 3ft,30. Thus there is a gain on a train of ten carriages of from 20ft,67, to 23ft,95.

The pressure between the buffers is obtained by a screw socket with right and left hand threads *m*, placed on the draw-bar. This ends against the middle of the first intermediate cross beam, the extremities of which receive also the india-rubber buffer-spring. The discs which constitute the draw-spring, which has a very small travel, have their thrust taken by the inside longitudinal beam *l*, and by the diagonals *c* which form a cross. The middle part alone of the frame is subjected to strains in the two directions.

This mode, which renders the coupling difficult and requires the porters to get underneath the carriages, is only admissible for trains the carriages of which are rarely changed, and this greatly restricts its application. It does not seem besides to give the passengers the same guarantees of safety as the ordinary mode, in the case of which slight shocks are not likely to do any harm. On the other hand the reactions are thus avoided, produced by the return of the springs; the travel of which is perhaps too much exaggerated in France.

137. *Coupling of American Railway Stock.* — American stock does not exclude the use of the appliances described above, but it is rarely provided with them. The appliances for buffing are completely absent, and those for drawing are greatly simplified. The frame carries a continuous bar *b*,*b*, (Pl. XVI, *figs.* 23 to 26), holding by a stirrup, a spring formed of straight plates all of the same length, the ends of which enter into foot steps bolted on to the frame. The rod terminates at each end by a small

fork, the branches of which *f,f*, have each an eye through them. The coupling is done by a short bar B, attached by a bolt to the rod of each vehicle. The rods and the bars thus form an articulated chain, which is at the same time rigid and to which each vehicle is attached by means of the spring R, subjected only to the effort required to draw the vehicle itself. This method has been applied by Mr *J. Edwards Wilson* to the carriages of the Indian Branch Railway, with this sole difference that instead of one spring there are two R, R, placed on either side of the middle axle, which is on the same level as they are (Pl. II, *figs.* 9, 10 and 11).

No provision is made for shock. This ought, of course, never to be produced in shunting: this mode of coupling requiring that operation to be done with great precision and deliberation. If a portion of the train is uncoupled to take on a waggon, the waggon must be brought up close with great care, and must the coupler who guides and introduces the bar, to put in the bolt, just hit the instant that the eye of the bar and that of the fork correspond.

This condition has its advantage; the porters are forced to pay attention to the stock, and to learn habits of care little evident in station operations, which thus enter for a large part in the depreciation of goods-stock. It is true at the same time that on lines of large traffic, the necessity of rapid working overrules every thing else.

This method of coupling can evidently be applied as well to ordinary stock, as to the American stock. It has, in fact, been so applied (Pl. XVI, *figs.* 23 to 26); but it disappears daily. When two vehicles very unequally loaded are coupled together, the bar had a notable slant, and in case of the least heavy waggon slackening speed its tendency to lift up by pushing the following one was much greater, than in case of buffers with rods always horizontal.

According to Mr *Krauss* running off the line due to this cause was pretty frequent at the entrance to stations on the "North Eastern" of Switzerland, up to the period when the stock was provided with buffers.

Altogether, the application of buffers with springs is incontestably far preferable, especially for passenger-carriages, and the consideration of their running in trains made up of ordinary stock leads them also to be placed on waggons. The "Central" Swiss, the stock of which is often mixed with that of the "Eastern" of France, is in the same position. The application of buffers is not, besides, indispensable. A compound coupling-bar, that is to say, bearing at one end an eye into which the hook of the French carriage is hooked, may be strictly accepted. A stirrup *l* (Pl. XVI, *figs.* 24 to 26), stops the bar from jumping and leaving the hook.

The great length of the American carriages renders them little suited to coupling up close, especially with buffers of the ordinary distance apart. The inconvenience of the rigidity, can be diminished by an arrangement applied to the long carriages already cited (22), of the "Metropolitan" line. The buffer rods abut against the extremities of a beam B (Pl. III, *fig.* 13), the axis of oscillation of which transmits the pressure to a single buffing spring placed along the axis. (In the carriages in question, this spring is *Sterne's* pneumatic spring). On a curve the axis of the carriages freely incline to each other, and the rectangle $a\ b\ c\ d$ formed by the two beams and the buffer rods, has no tendency to lose its forms (fig. 13). But the efficiency of the pressure between the buffers with respect to the swinging motion (126) is thus a great deal less than with the forced parallelism of the buffer rods, and of the axes of the frames.

CHAPTER III.

GOODS STOCK.

§ I. — General characters.

138. At the origins of railways, their immense bearing on industry was misunderstood, and formally denied by a great many otherwise enlightened minds. They were looked upon as a sort of minister of luxury accessible only to travellers; an error all the more singular, as railways at their modest outset, were nothing else than valuable auxiliaries to mineral industry, the instrument of under-ground traction for materials the most cumbersome. It was not a question, then, of speed, but only of the reduction of the effort of traction, that is to say of the property by which these iron roads, adapt themselves so well to the conveyance of heavy goods.

Later, the truth was obliged to be owned : that no conveyance whatever is beyond the capacities of the iron roads; that, by the concourse of advantages they offer, they can compete with navigation, contenting themselves with tariffs, which had never been dared to be hoped for, and yet find their profit therein.

At the present day, and although the possible limit of the tariff has not yet been attained, it would be wearying to insist on the immensity of the service rendered by railways in the conveyance of raw materials, as well as in the transport of finished products. Agriculture and industry live by means of them, as they live by agriculture and industry.

The establishment of goods rolling-stock is a purely industrial problem. Here we have no longer to deal with conditions of comfort and security, which are overruling in passenger-stock. But the problem is not less complicated; loading and unloading must be easy, no disturbance of the load must occur during running; matters conveyed must be protected against the weather, if their nature and the condition they are in require; finally

the dead-weight must be reduced without compromising the solidity or the durability of the stock.

139. *Disadvantages of special vehicles.* — The variety of freights that railways have to carry led at first to multiplying the types of the waggons. It was desired to appropriate in the best possible manner the instrument to the work; but this was soon recognised to be an erroneous idea. Besides the disadvantages of the great multiplicity of types as regards construction and maintenance, this complication went quite away from its aim. It frequently happened, especially on account of the prolonged absence of vehicles gone on to other lines, that in the stations, the type of waggon corresponding to the freights to be carried was wanting; others had to be made use, built for other purposes and consequently ill-suited for the service for which they were taken. Instead of systematically specialising a system of constructing waggons, with the view of a determined category of freight, it is endeavoured on the contrary, now-a-days, to reduce the number of these specialities, and multiply the types which by the fact that they are not intended for anything in particular, are suitable for very varied uses. The low waggons or platforms (146), the open waggon with vertical sides of from 2 ft, 63 to 2 ft, 28 (143), and the covered waggons (148), suffice in general for the mass of freight, and constitute under divers denominations the greater portion of the available stock. The waggons called : special, have themselves no longer in general a regularly specified use and may be applied under divers conditions.

140. *Rules for the use of the stock. Examples.* — I take from the general order No 12 of the traffic department of the "Eastern" of France, the principles laid down for the use of stock running at a low speed :

. . . .

Act. 25. As a general rule, the goods sheds and termini should make use of goods-waggons without other distinction as regards the freights, than that between covered waggons, and open waggons with tarpaulins, etc.

In the particular cases, where special stock might be wanted attention must always be paid to the indications and prescriptions here-under :

26. *Waggons for the Customs' service.* The waggons (N) indicated in the list as intended for service of the Customs and so marked, must be more particularly kept for the transport of goods bounded.

These waggons, specially arranged so as to be sealed and padlocked, bear the inscription *Customs' service.*

Failing these special freights they must only be loaded with goods destined for frontier

stations, where a Custom-house is established, or for points situated in that direction. They ought never to be employed for the traffic of the internal branches of the system.

There is no question there of a speciality properly so called, with relation to the nature or the state of the freights to be carried.

Act. 27. *Waggons* (N) *with hinged panels.* They may be employed for the service of the Customs. The fastening of the panels must be the object of the most particular attention on the part of the stations from which they are sent.

The same observation as above.

Act. 28. *Waggons* (N) *with curtains.* The waggons (N) with curtains and with hinges are regularly used for the transport of live-stock.

30. *Acid waggons* (J); special.

31. *Milk waggons;* special.

32. *Waggons for powder, and munitions of war.*

. . . .

Although, these waggons are more particularly set apart for the conveyance of powder, the stations where they are lying by, may employ them for other freights, but only when there is a great dearth of waggons, and taking care to load them only for destinations in the division to which they belong.

33. *Waggons with tressles* (E) *for turn tables;* special.

34. *Ice waggons* (I); special.

35. *Waggons for large timber.*

According to the dimensions of the large pieces of timber, the following waggons are employed namely:

P, No 1, ten tons, for timber 33 feet long;

P, Nos 3 and 7, to 16 tons, for timber 52 feet;

SS, coupled and with a perch, for timber the length of which does not exceed 59 feet. They may be loaded up to 20 tons;

P, No 2, and 8 to 20, to take 20 tons and timbers of 72 feet in length.

36. *Waggons for a mass of great weight which cannot be divided.* The waggon PP can receive loads from 20 to 22 tons. These loads should form one undividable mass, not exceeding 16 ft, 4 long by 8 ft, 20 in breadth and 7 ft, 38 in height, or 9 ft, 84 in breadth and 6 ft, 56 in height.

39. The waggons P and SS with perch, being special for the transport of timber of large dimensions, ordinary waggons must not be coupled on for loads having to rest on two waggons at a time, unless with the written authority of the traffic manager or local superintendent. The waggons SS may be uncoupled and loaded with other kinds of merchandise besides wood, when that freight is wanting. Care must be taken so to arrange the movable parts with which they are provided, as not to interfere with the load; and especially not to endanger its stability.

To the specialities mentioned in these instructions, the list of the rolling-stock only adds the following:

1. The flat waggons (E) without sides, specially for rails;

2. The waggons with bodies (O) with traps, for coal, a type which is now disappearing (149);

3. Coke waggons (H); without ceasing te be devoted to this use, these waggons with sides, (Pl. XVII, *figs.* 13 to 16) are now utilised also for the transport of live stock, concurrently with the covered waggons having movable panels or curtains. This application of coke waggons, taken from the German and Swiss railways, accepted at first with some repugnance possesses in reality no disadvantage.

General order No 17 completes the preceding instructions, by some detailed instructions which it is useful to reproduce at this time, because they give in precise terms the precautions to be taken for restricting the specialisation of the vehicles. They would besides not be in their place in the following parts of this work.

. . . .

Act. 41. The provisional way bill being made out, the waggon must be taken best suited to the nature of the load, always giving the preference to closed waggons over open ones.

44. The heaviest objects must be put in the bottom of the waggon, equalising as much as possible the load on each axle.

Care will be taken to avoid placing one near the other packages which by their contact, would be liable to damage each other; placing, thus, oil along side of bales of stuffs; wrought or cast iron against bales of cloths, etc., which might be damaged by the friction.

47. In order to prevent, during the operations taking place along the road, casks knocking up one against the other, and thus driving in their heads, they ought always to be loaded sideways, and not end to end; they ought to be carefully, wedged up either with fagots and stakes tied together, or simply with strawbands twisted tight; the use of stones is formally interdicted, because they wear the stave against which they are pressed, and cause in course of the journey a leakage likely to be of great importance.

48. Loading very large casks in closed waggons (N) will be avoided as much as possible and if these are obliged to be used for this purpose, the casks must be placed so as to exert no pressure on the sides of the waggon, which might become dangerous if the load consisted of two rows of casks, one above the other; the casks of the upper row tend to get down between those of the lower row; in this case the wedges destined to prevent their rolling, must be as strong as possible.

49. The goods that damp can damage, such as zinc, sheet iron, sugar, hops, flour, calicoes, tissues, etc., are only to be loaded on platform trucks or in uncovered waggons when the station is entirely without closed waggons, and if these cannot be procured without exceeding the time which the freight has to be forwarded in.

If it is an absolute necessity to employ platform trucks, for these loads, as well as for all those that the rain can spoil, the goods must be covered with a thick layer of straw before putting on the tarpaulin, laying that with care equal to that exercised in

loading road-vans. This straw, which preserves at the same time the merchandise and the tarpaulin, will be gathered up with care, by the receiving stations, and if it has not got wet, must be employed again for the same purpose.

51. The stations take in general too few precautions in arranging the loads of goods in the waggons, in the belief that they are not likely to be disarranged during the journey. It is not so. Starting, stopping, shaking on the way, are powerful causes of disturbance, and, consequently, of damage, which ought to be prevented at starting.

It is impossible to previously indicate the precautions to be taken to preserve each kind of goods from the damage which is most to be feared for it. Those in charge of loading, will be able to take all the necessary precautions, if they do not lose sight of the fact, that the waggon is exposed to shocks, sometimes very violent, and that being so, all the packages should be always kept in their places and fastened, each one at the same time, in the conditions peculiar to it. Thus, marble in slabs, mirrors, window glass, ought to be placed upright and firmly kept in this position, etc.

52. The stations must never rely on the tarpaulins for consolidating the load. The tarpaulins are solely intended to protect them against wet. The load ought thus to be completely fastened down by the ropes, tightened by twisting with a piece of wood, before being covered by the tarpaulin...

55. Waggons loaded with sacks of flour, bales of cotton, bark, hay, straw, or any other cumbersome merchandise, must be passed under the loading gauge (7), and tied down before covering in, to avoid by all possible means any damage to the tarpaulins.

141. The "Méditerranée" system possesses at present, 1869, on 2,480 miles open for traffic, 44,256 goods-waggons, thus divided :

1. *Without special purpose.*

Platforms	5.216	12.978
Trucks	1.810	
Closed and covered	5.952	

2. *For special purposes.*

Coal	19.598	29.912
Cattle	6.994	
Cut stone	1.889	
Coke	854	
Wood work	532	
Coal tar	30	
Two storied	15	

3. *Service.*

Ballast	1.294	1.366
Succour	49	
Conveyance of plate layers	15	
With double trucks	3	
Snow ploughs	2	
Water tanks	3	

This classification seems to give very considerable prominence to special waggons, but the purposes indicated are very far from absolute. Thus, the coal waggon is now confounded with the open truck, the cattle waggon with the closed waggon, and the cut-stone waggon with the platform, excepting in its stronger platform, which does not of course exclude it from the same uses as platforms are put to.

142. The "Northern." of France has, for 882 miles in working, 16,327 low speed waggons, thus distributed :

Platforms	2.375	4.289
Open trucks	51	
Closed and covered	1.550	
Brakes 12 tons	310	
Special waggons.		
Coal	7.776	11.432
Cattle	1 302	
Coke	1.300	
Timber	478	
Stones	501	
Sheep	75	
Service waggons.		
Ballast	558	606
Succour	32	
With tressels for turn tables	16	
		16.327

The great number of waggons set apart almost exclusively for the carriage of coal and coke, is explained by the exceptional position of the "Northern" of France, for which coal constitutes such an important element of traffic, in spite of the competition of the canals : but of course, there as elsewhere, these waggons can and do serve for very varied freights.

143. The reduction of the specials combined with an expeditious system of distributing the stock amongst the stations, allows the requirements to be met without exaggerating the available stock. This distribution is one of the points which require on the part of the traffic department the most looking after and activity during the periods of plethora of traffic. The observations made by the "Eastern" of France in answer to complaints of the insufficience of its rolling stock will be read with interest :

" The distribution of the stock that is to say the sending on of empty waggons necessary for the conveyance of goods is the object of our daily attention, of our incessant care because it is without question one of the parts of working traffic which present the most difficulties.

" In effect, not only are the arrivals and departures unequal, which form the local traffic of the 400 stations and more, which we have to serve on our system of lines, but more often the nature even of this traffic is such on these different points, that the stock which has brought in goods is unsuitable for the loads which have to be sent out. Thus at *Ars-sur-Moselle*, for example, the waggons which have taken fuel and minerals, cannot be utilised for the carriage of iron. It is thus that our rolling-stock which runs down towards *Paris* loaded, is obliged to go back empty for distances often considerable, without being able to be utilised. It is an evil, which, in spite of all our endeavours, we have not been able to remedy, compelled as we are to follow and to satisfy the currents of traffic.

" Besides, the irregularities of freights which we are obliged to undergo, puts us often in very difficult positions. In effect, during the four last months of the year, we have to meet, not only the despatches of commerce and industry which are produced all the year round, such as fuel, stones, irons, raw materials in general, and manufactures; but also the agricultural products, such as : oats, wheat, barley, cereals in general, beetroot, pulps, sugars, brandies, wines, hay, straw, which after harvest, commence to be sent, in large quantities. Add to this the conveyance of animals, which at that season are produced on a considerable scale, not only from the interior of France, but which come to us also from Germany, Switzerland, and Prussia, to our frontier stations of *Strasburg* and *Forbach*, and you will comprehend the frightful disproportion which exists between the freights of these last months and those of the eight preceding ones. Moreover, the tillages of the ground having slackened, a great many agriculturists place their labour and their horses at the disposition of the different industries. Hand labour being cheaper, the conveyance by carts being lower, the manufacturers take advantage thereof to push on their works, often behind; the large factories, seek to complete and deliver their orders on hand before the end of the year; each in a word, increases its production, and that explains the dearth of waggons, which is generally produced on all railways during the months of September, October, November and December.

" To meet this situation which is independent of us, we have increased our rolling stock, and are still increasing it : in 1865 we constructed 1,505 waggons, and 1,894 in 1866. At the 1st January 1867 we had 16,887 goods-waggons exclusively reserved for our traffic department, for I do not include in this number the stock which serves for the special business of the way and works and locomotive departments, and which we utilise, however, in times of pressure. Also at certain periods of the year, we have a notable quantity of waggons standing idle, while at other times we can hardly meet the demands on us.

" If at least, we found at these times aid and assistance on the part of commerce and industry it would be easy for us to remedy this dearth of waggons; far from that, in the fear of not getting stock, the senders force their demands in an unreasonable manner, while those receiving goods do not wish to increase their means of removing them, leaving their goods on our platforms, blocking them up and hindering thereby the unloading of waggons, and aggravate in fact the situation, by increasing the dearth of waggons. "

§ II. — Technical details.

144. We shall dwell but little on the construction of goods-stock: reserving the details, for vehicles serving for certain special loads, which by their nature, their dimensions and their mode of stowage, may affect more than others, safety in running or that of the *employés*, and call for particular precautions.

Goods-stock is constructed, naturally, according to the same principles as passenger-stock, but is rougher. The frame, sometimes of wood (Pl. XV, *figs.* 19 and 20; pl. XVI, *figs.* 1 to 3 and 7 to 10) sometimes in iron (Pl. XIV, *figs.* 18 to 23; pl. XV, *figs.* 4 to 8) sometimes compound (Pl. XVI, *figs.* 13 to 18) is analogous to that of carriages, and its mode of construction is as has been already said, in relation to the system of appliances for drawing and buffing. The bearing springs are more rigid, shorter, and have a greater original camber. The longitudinals are often placed on these springs without joints and with the interposition of a simple shoe q, q, with rims (Pl. XIV, *figs.* 14, 15, 18, 19 and pl. XVI, *figs.* 13 and 14). This arrangement, more economical, simplifies the lifting of the axle-boxes, but it has some disadvantages, notably for running through curves. The axles can only take advantage of the play allowed to the guard-plates by overcoming the friction of the shoes on the ends of the springs. It is true that the frames are shorter, and the distance apart of the axles less than in passenger-carriages. However the *Dresden* meeting pronounced against suspension without articulation (*). Spring clips are in effect in nearly general use in the goods-stock of the German railways (Pl. XV, *figs.* 1 to 3, 5 and 7; pl. XVII, *fig.* 1).

Guard-plates, if too weak are subject to twist out of shape; and the vehicle tends then to run off the line. The stouter dimensions adopted now-a-days for these pieces, put this danger aside, but also, in consequence of their stiffness, the shocks produced in shunting and so on, are brought with greater intensity on to the axles, a circumstance which must be taken into consideration in fixing the dimensions of the axles. It is clear that all the elements ought to be suitably proportioned.

The guard-plates of the trucks with iron frames of the "Eastern" of France present a peculiar and simple arrangement. The two struts and the lower

(*) Vereinbarungen. Art. 163.

tie or strap, are formed by a single flat bar $p\,p$, rivetted at the two ends on to the bars of the longitudinal (Pl. XVI, *figs.* 1 and 2).

The buffing and drawing appliances are equally simple, at least in general, for we find several examples of the application of the large springs of passenger-carriages (Pl. XIV, *fig.* 20; pl. XVII, *fig.* 13), only with a reduced travel of the buffers. A long travel may prevent the breaking of couplings caused by starting too sharply; but it might also cause it in very long trains, because it increases the recoil of the waggons after pulling-up, when the train, after compressing by the slackening in front, springs out again by the reaction of the springs.

More often, special springs are applied to the two different efforts, which allows the length to be reduced, and consequently the section of the draw-spring if it be in steel with staged plates. The buffing is done then, by india-rubber springs, or by *Brown's* or *Baillie's* springs.

Examples of this arrangement are found on the "Western" of France. The two draw-springs are placed on one side and one on the other of the middle cross-beam of the frame, they are short, and coupled by clips, so that the waggon is drawn by the middle of the cross-beam. The india-rubber washers and the piston which presses them are placed in boxes bolted on to the outside face of the end cross-beams and consequently overhang.

In waggons with dead buffers, which become less numerous every day, the buffing is taken by the projections S, S (Pl. XVII, *figs.* 7 to 10) of the side poles strengthened by blocks of wood. As it has been said, there is always even then, unless in certain waggons joined together and carrying one and the same load, (159) elastic drawing. When a waggon is not provided with such fixed appliances, it can be replaced by M. *Lasalle's* tightener, a sort of portable dynamometer D, interposed between the two drawhooks (Pl. XVII, *fig.* 7) and provided in the middle with a ring and two stops, which limit the versed-sine. But this instrument, inconvenient and dangerous for the porters to handle, is little used now-a-days.

For a long time coupling waggons was done by pieces of chain joining the coupling-hooks. Now-a-days the application of screw links, (126), similar to those of passenger-carriages becomes more and more general. In Germany the *Vereinbarungen* expressly recommends this. In France the goods-stock of the *Paris and Méditerranée* system is almost entirely provided with screw-couplings; this is a notable improvement, but it is of consequence that the joints of the blocks forming the nuts of the screws should be quite free; when rust renders the system rigid, the link is subject to get off the hook, by jamming back, or by the simple reactions after stopping.

The surest means of preventing rigidity is to increase the play of the joints.

145. Among the accidents which railway servants are exposed to, none are more frequent than those from buffers. During station operations, porters are frequently caught between the buffers of two consecutive vehicles, and but too often receive mortal injuries thereby. They have to place themselves against the buffers in pushing waggons by hand, and they must get between the waggons in coupling and uncoupling. These last operations have nothing dangerous in them, in general, unless in the case, which we shall come to (155) of projecting loads. That excepted, getting in between the buffers is only attended with danger to inexperienced men, who do not guard themselves, against the effects of the reaction which follows a pull-up; if they seek to get out just at the moment that reaction is taking place, they may get knocked over by the shock and fall under the wheels. There would be no great advantage however as is often supposed in dispensing with the men getting between the buffers to couple or uncouple; and it would have little influence on the number of accidents from buffers.

As an example of the arrangements imagined for coupling from the sides, we shall allude only to that of M. *A. Meyer*, shown by *figs.* 33 and 34, Pl. IX. Each of the coupling-links m, is connected by two jointed bars b, b' to two nuts q, q', working on a right and left hand screw, turning in bracket-blocks p, p', p''. By turning the screw v, v', by means of the handles μ or μ', the blocks q, q' are brought together or set apart according to the direction the handle is turned in, and the link thus set forwards or backwards.

To couple, the bars $b\,b'$ being as close up as possible, the link m is let down on the shank of the coupling hook of the other waggons; by turning the screw so as to open the bars, the link catches into the hook, tightens on it, and so presses the buffers together.

To uncouple, the handle is turned the contrary way; the link leaves the hook, and as soon as it is free, the turning of the shaft lifts up the whole thing, link and bars.

The guard-chains having to be done by hand, must in this case, be placed outside the buffers.

This apparatus is complicated. It solves the problem; but the solution is not of the use sometimes attributed to it. The external position of the guard-chains is of itself very objectionable: with a considerable distance between them, they would hang very differently in curves, and would thus act very unequally, in the case of the coupling breaking.

146. *Platform trucks.* — Flat waggons are: either absolutely without sides, or with sides only from 8 to 16 inches above the frame (Pl. XVI, *figs.* 13 and 14; pl. XVII, *figs.* 1 to 6). These sides may be either fixed or on hinges, with strap catch fastenings; but the costly maintenance of the hinges and other iron-work restricts more and more the use of these waggons with falling sides, and they are often handed over by the traffic department to the "way and works", for ballast waggons. Those with falling ends but fixed sides, which allow of long things being loaded, and when required the joining of two together, are more used.

Platform waggons may, like trucks, be constantly provided with their equipment (ropes and tarpaulins), or only receive them when the nature of the load requires them. The first way is the best; the tarpaulins, when not in use, are then rolled up and strapped down to the sides of the waggon. The porters often omit to roll them up tight, and to strap them well down; the axle-boxes thus get covered over, and the lubrication is difficult, or even impossible. When loose tarpaulins are employed, they are kept in stock at the principal stations, and given out as required. On the large lines both ways are generally in use.

The covers are a costly accessory; in leather they are durable but dear. Those of cotton are more used; and they are also made of spun silk. Both are soaked with an oily stuff which protects them and renders them impermeable, but does not prevent their rapidly destroying.

147. *Trucks or waggons with open bodies.* — This is the type which, arranged according to requirements, is applied to the most varied freights (Pl. XIV, *figs.* 18 to 23). Out of a total of 42,890 vehicles for slow goods-traffic, the "Méditerranée" system has 20,587, a figure which includes, it is true, 17,598 vehicles principally but not exclusively devoted to the carriage of coal.

The ends, frequently gable-shaped (Pl. XVI, *figs.* 1 to 12) are pretty often jointed together at the top by a longitudinal piece or ridge, which ties them together, and allows the cover to be put on easier. When it is only wanted to strengthen them, struts are also employed butting against the sides, but this manner of strengthening the ends, is only applied where there is a continuous upper longitudinal piece; the doors are then completely enclosed by a frame, which is inconvenient for working.

Waggons differ often from passenger-carriages, by an essential item of construction: the consolidation together of the body with the frame (63), which takes the assemblage of the uprights; a simple and economical arrangement for construction, but less advantageous as regards maintenance.

The manner in which the doors of trucks are arranged, is an important point. These are ordinarily two hinged flaps; sliding-doors generally preferred for closed waggons not being applicable in general, to uncovered waggons; the dust from the load, from coal, for example, would choke up the hinges, and render them difficult to work. This is troublesome. The opening of the flaps causes at times, accidents through the negligence of the porters, who do not take the trouble to put on the fastenings of the doors of empty waggons, and content themselves with putting the flaps in their places. The wind caused by a train running on the other line opens them, and they may then encounter the vehicles passing on the other line.

In the "Eastern" of France, waggon, for example, (Pl. X, *fig.* 12, and Pl. XVI, *figs* 1 to 6), each flap is 2 ft, 43 wide, and entirely open, projects beyond the body 2 ft, 70; the body itself being 8 ft, 53 wide, the edge of the flaps extends beyond the axis of the rail, by:

$$\frac{8\,\text{ft},53}{2}-\frac{4\,\text{ft},92}{2}+2\,\text{ft},70=4\,\text{ft},50,$$

a figure to which must be added the projection of the lower bolt, or 0 ft, 25. The total projection over the space between the lines is 4ft,50 + 0 ft,25 — 0 ft,60 (half the breadth of the rail) = 4 ft, 65.

For a first class body, this projection is:

$$\frac{9\,\text{ft},18}{2}-\frac{4\,\text{ft},92}{2}-0\,\text{ft},10=2\,\text{ft},03.$$

A collision is then inevitable, the same of the projections

$$4\,\text{ft},65+2\,\text{ft},03=6\,\text{ft},68,$$

being in excess of the space between the lines, which is 6 feet on the old lines, and 6 ft, 56 on the new (7).

This is also neglecting the handrails and the door-handles which would be caught before the body, beyond which they project.

The flaps ought to be provided with very solid fastenings. In the waggons quoted, of the "Eastern" of France, it includes (Pl. X, *fig.* 12, and Pl. XVI, *fig.* 2), above, a hooking bar *b b*, and below, an espagnolette bolt *v*, fastening the flaps to each other and to the longitudinal.

Figs. 4 to 8 of Pl. XV represent a waggon entirely in iron, intended principally for coal traffic, and constructed at the establishment of *Schmidt* and *Comp.* at *Breslau.* This waggon, which has been well worked out, is greatly in use on the Upper-Silesia line. It will be sufficient to point out: 1. the

arrangement of the standards R, in U iron, carrying the hinges of the doors; these standards R (*fig.* 4) being continued and bent under the frame, possess much more solidity than those which are turned sharp under the body; 2. the door fastenings; the handle commanding both an espagnolette bolt e, and a catch v; 3. the very open angle of the extreme branches p, p, of the guard-plate, which independently of the solidity of the plates themselves, allows the spring straps m, m, to be attached thereto instead of on to the frame.

The same waggon serves for the conveyance of quicklime without any other modification than the addition of a cover.

The "Upper-Silesia" line has tried iron trucks without frame. The plate iron body took and tied together the whole: the spring supports, guard plates, couplings etc.; but experience has not pronounced favourably on this simplification.

148. *Closed waggons.* — These waggons are suitable for those goods which from their value, their nature, and their insufficient packing, have to be protected from the weather. Besides their more considerable dead-weight and cost, these closed waggons have the disadvantage of rendering loading more difficult, and of excluding ordinarily, the use of cranes. However in England, where the mechanical appliances at goods depôts are so perfect, covered waggons are very often used with cranes: openings being made, for that purpose in the cylindrical hoods which cover them.

The great advantage of closed waggons is to get rid of tarpaulins; but it is far from conducing to equilibrium. The number of these waggons should thus be strictly limited to the actual requirements of the traffic. It is, for example, quite disproportionate on the German lines, which would do well on this point, to follow the practice of England, France and Belgium.

The bodies are almost always now, parallelopipeds; the form with a semi-cylindrical top, first adopted in France, on the Southern lines of the "Méditerranée" system, is now given up.

Closed waggons have sliding doors (P, Pl. XIV, *fig.* 14) provided at the bottom with grooved rollers r, r, which run on an iron bar h, and above, by straps running on a rod t, they are thus kept up, if the bar that the rollers run on gets twisted. As to the panels of the body, they are either fixed for their whole length, or movable vertically between grooves, at their upper part (ω, ω, *fig.* 15). The fixed panels are suitable for custom's goods; the movable ones allow the waggons to be used for various goods, or

for cattle. By adjusting the sliding panels which is done on the outside by means of a notched catch o, jointed at *a*, the supply of air can be regulated according to the temperature.

The Belgian lines employ waggons of this kind, for two purposes (Pl. XIV, *figs.* 9 to 14) goods and cattle, entirely in iron, excepting the flooring. The frame is formed of two longitudinals, four cross-beams, and gusset pieces which allow the tie pieces to be dispensed with. Brackets fixed on the faces of the longitudinals, take the floor of the body; a tie bar, forked at each end, ties the cross-beams together, and transmits the effort of traction. The body is formed of plate iron panels, riveted on to external stanchions, in U iron, in one piece. Each of the four sides is furnished with a door; those of the ends *p*, *p*, fall down, and those of the sides slide: the side panels also slide up and down. This waggon weighs 6 tons, 8, that is to say, a little less than the similar waggon in wood.

In spite of the very general preference of iron for frames, in Germany, many companies are against its application to the construction of the bodies of closed goods-waggons. The sides, they say, get knocked in, the iron plates rust, the paint scales off, and the iron oxidises. Their conductibility is objected to, and the mischievous results that might happen through them to certain sorts of freights. Thus it is objected that bodies in sheet-iron do not offer suitable hygienic conditions for the conveyance of troops and horses: a consideration which always comes in, on the other side of the Rhine, to the study of questions of rolling-stock.

§ III. — Special Freights.

149. *Coal.* — Special waggons, provided with trap bottoms for discharging on a staging, were long set apart for coal traffic. Pyramidal bodies at first in use, gave place to bodies with vertical sides; the traps also disappeared by degrees, especially in France. Unloading on a staging is expeditious, but our tender coals cannot stand it without a marked increase in dust. The "Eastern" of France which had greatly extended the use of the stages, has successively suppressed a large number of them. Besides the traps present as regards the working of the lines, drawbacks and even danger. Sometimes they get open while the train is running; the load falls on the line, and may cause the train to run off.

The traps are sometimes hinged crossways, as in the Prussian pyramidal waggon (Pl. X, *figs.* 14 to 16); sometimes hinged longways. Each flap is

kept closed : 1. in the first case by a lever L having its axis of rotation I, on the middle cross-beam of the waggon, and held up at the other end by a catch E, and which brought under the cross-beam lets down the flap V, two counterweights P, P kept up by when the waggon is empty. Notched bolts *l*, *l*, keep the levers L, L, from getting out of place by the effect of the shaking of the waggon. 2. In the second case, by a fork, which rests on the shoulder of a hanging bar, which a stud keeps vertical, and which, moved out of that position leaves the flap free.

But whichever of these two arrangements may merit the preference, there is a third one which is certainly the best, in general, that is the suppression of the traps.

150. *Transport of cattle.* — If goods properly so called, have to be preserved from damage on the way, considerations of humanity ought to intervene in the material conditions of the carriage of cattle. *Grammont's* law which has fixed in France a moral principle, and given satisfaction to a right feeling of commiseration for all that lives and suffers on the earth, might receive more than one application in the transport of cattle in *full* trucks, and often much more than full trucks. The avidity, as narrow-minded as it is barbarous of the senders leads them often to jam the animals in together, which condemned during long hours to absolute immovability and deprived of water and food, suffer cruelly. In unloading sheep, several are often found suffocated by the manner in which they have been crammed in one on the other.

The Prussian minister of commerce has recently taken up this abuse, which is inexcusable in civilised countries, and has specified measures for preventing animals being crowded into trucks, and to insure their being able to drink at the stations.

A circular of the minister of public works in France (29th. November 1869) following up this initiative, instructs the Government inspectors of railways to investigate, if similar arrangements should be applied in France.

151. *Commodities which easily spoil.* — Among the provisions which require, for long journeys and during the hot weather, carriage specially appropriated to them, may be taken dead meat and beer.

a. *Dead meat.* — The Western States of America despatch considerable masses of meat to the towns on the coast. The living animals would suffer and would undergo a considerable depreciation by long journeys; but, slaughtered, they require to be kept at a low temperature. The bodies of the

waggons, mounted on two four-wheeled trucks and containing from 9 to 11 tons of meat, are formed of two envelopes of pine with an interval between them of from 2 3/4 to 3 inches filled with cork. At the two ends are compartments filled with ice; a circulation of air created by a sort of fan, which is set in motion by a small turbine in zinc fixed on the same axis, and placed above the roof, keeps the temperature within at 46° (F.).

This mode of conveyance has allowed the slaughter-houses in several large towns to be done away with, and improved the quality of the meat.

b. *Beer.* — Beer is one of the most susceptible productions. Too high, the temperature develops in it abnormal fermentations; too low, the quality is equally impaired. The limits are thus very restricted.

In northern countries, where ice is at a low price, the brewers keep in the cellars containing their stocks of beer a low enough temperature by accumulating heaps of ice therein. Conveyance to a great distance requires analogous precautions.

During the exhibition of 1867 at Paris, a great *Vienna* brewer, M. *Dreher*, who desired that the quality of his products should be appreciated in all their purity, organised a method of conveyance by refrigerating waggons, which has continued in working ever since. *Fig.* 1-3, pl. XV, represent the arrangements of these waggons, which bring the beer direct from his breweries to *Paris*; the temperature of the beer is kept at 40° (F).

The conditions to be fulfilled were : 1. facility of loading and unloading; 2. the obligation of leaving the beer to itself during the journey, under the seal of the Customs ; 3. the complete separation of the space containing the ice, and easy access to that compartment by means of special openings, access necessary in the case of delay to the train, when more ice has to be added. 4. the situation of the ice above the beer, so that the latter should be always surrounded with the coldest, and consequently the heaviest air.

At the request of M. *Dreher* who offered to the *Staat's Bahn*, to bear the cost of fitting up in this manner a certain number of closed waggons, M. *Bender*, the engineer of the company, adopted the arrangement shewn by *figs.* 1 to 3 of plate XV.

The sides are double, and the spaces filled with straw mats, and chopped straw. The ice is kept in two sheet-iron reservoirs 0 in,08 thick, strengthened by three arched frames φ, φ, φ, which dispense with intermediate supports. The water from the melted ice runs off by four pipes, *t*, *t*, *t*, *t* turned back so that the external air cannot get in. Thus fitted, the waggon weighs 2 tons,5 more, and costs £ 80 more. The load is 1190 gals. During the hottest weather the reservoir receives 1 ton, 5 of ice, which is put in a little

before the barrels of beer, if the waggon has got warm. On arrival in Paris, after five days, the temperature is 41° (F), and the reservoir still contains 10 cwt of ice, even in the hottest weather. Sent back as quickly as possible, the waggon arrives at Vienna with its temperature at 38° or 40° (F), with a little ice remaining, and can be reloaded immediately.

This arrangement can certainly be simplified; in doubt, and in order to assure success, and beyond all doubt, too many precautions were taken. The cost and the dead-weight could certainly be notably reduced. These costly expedients, are only necessary besides, for very long distances, such as this in question (868 miles, through several countries); and can be got rid of for even considerable distances, 3 to 400 miles. For example, for the conveyance of beer from Alsace to Paris, the journey as well as the collection and delivery is done with sufficient celerity to avoid exposing the beer too long to heat enough to spoil it.

This freight, in the course of some years, has become remarkably extended, and has developed among the Parisians a decided taste for beer, which so indifferent in Paris, was only consumed there in small quantities, long as there was only the local production to fall back on.

At the present time, the Strasburg brewers send out a whole train every day, which does the journey in a little less than twenty hours.

§ IV. — Freights requiring special precautions from the point of view of safety.

152. Many matters require precautions, by their very nature: such are, inflammable and *a fortiori*, explosive substances.

But there are also matters quite inoffensive in themselves, the transport of which only presents difficulties, or requires precautions, on account of their large mass, their low density, or their shape.

Loads cannot always be kept completely in by the sides of the vehicles; and sometimes they have even to be supported by two vehicles at a time. Precautions must then be taken against any derangement of the load, which might cause serious accidents, either by exceeding the limits of the loading gauge (7), and striking against vehicles on the other line, or by falling out and creating an obstruction on the line. It will not be without use to bring forward some of these facts. Accidents are lessons, dearly paid for by the victims, by which we must try to profit.

Loads which are very voluminous on account of the small specific gravity

of the material, and the necessity of utilising the waggon, hay, for example (which is always compressed now-a-days), wood for burning, charcoal (classed also amongst inflammable materials), etc., are supported by means of binding ropes. There is nothing particular to say about this, from the point of view of stability of the load, excepting that it is prudent, for these substances, not to go to the extreme limit of width allowed by the loading gauge (7). A service order of the "Eastern" of France (13th. July 1866) prescribes for these materials, a space of at least 4 inches to the left between the vertical rods of the gauge and the sides of the load. Thus there is in fact, a special gauge applied to them. We shall return to the measures prescribed with reference to inflammability.

153. *Dressed stones.* — Platform waggons without sides are the most convenient for the conveyance of dressed stones. But their use may cause grave accidents.

On the 20th. March 1868, on the line from *Paris to Strasburg*, a block of stone of 11 cub. ft, 65 fell from a platform waggon in a goods-train, and blocked up the other main line, upon which came up, at the very time, a passenger train, out of a curve, so that the driver was unable to see the obstruction, until he was quite on it. An accident was thus inevitable, and that without involving any other responsibility, than that which resulted from improper loading. The concussion was very violent, and cost four people their lives; nineteen also were injured.

These platform trucks are provided with cross-bearers, 4 ins, 72 above the flooring, leaving thus a space which is convenient for putting on and taking off the slings used for loading and unloading. The block was resting on one of these cross-bearers, and in order to keep it up (wrongly) level, the height of the bearer had been made up with wedges of stone, which were either crushed or displaced. Placed thus in a positive sloping towards the outside, the stone had slipped by the shaking of the waggon, and had ended by falling off.

In consequence of this accident the Railway Department recommended that cut stones should only be conveyed in platform waggons with longitudinal sides rising at least 3 ins, 15 above the floor or upon the cross-bearers. As to the end, they would have the drawback, if they were fixed, of prohibiting the carriage of long bars, rails etc., on platform trucks shorter than themselves. They are besides unnecessary for the conveyance of blocks of stone. It is sufficient for these, that they rest by one end on one of the cross-bearers, and by the other on the floor of the waggon, and butting

against another cross-bearer, so as to prevent their sliding longitudinally.

With their small projection, which besides is sufficient, the required sides, do not in any way interfere with the loading and unloading, always done by means of cranes.

154. Without having recourse to these sides, blocks can be prevented to a certain extent, from falling off, by hollowing out the upper surface of the cross-bearers, with which the flooring of the waggon are provided. Out of a total of 7,105 platforms, the "Méditerranée" possesses 3,529 for the transport of stones, namely : 2,719 with fixed sides and falling ends ; 560 with falling sides and fixed ends; and 250 without sides, but with hollowed cross-bearers. A recent accident similar to that on the "Eastern" line, but fortunately without the consequences, proves that this arrangement does not offer complete guarantees, at least for blocks of small volume, with the small dish given to the top of the cross-bearers. To reserve the platforms in question for large block, would be making what is wished to be avoided, a speciality: so that sides will be applied to these platforms as to the others.

155. *Sheet iron, castings,* etc. — In 1867, a load of sheet iron 11ft,5 long by 4ft,92 broad, placed on a platform truck and fastened down by binding ropes, caused an accident on the "Eastern" of France, this time without harm, but which might have been serious. The top sheet getting out of place struck against some waggons standing on the next line, damaged them, and galling more out of its place by these shocks, knocked against the abatment of a bridge, cut the binding ropes and smashed in a waggon.

The 13th. Dec. 1868, a cast iron rolling mill cylinder, weighing 10 tons,30, was sent off from *Rive-de-Gier* on a waggon with six wheels (PP), capable of carrying 15 tons. This cylinder having broken the stanchion on the side next to the other line, fell out between *Grand-Croix* and *Lorette,* blocked up the other line; was caught by a passing train, which got off with some damage to its engine and break van.

The loading was badly done. The waggons PP, have, like those which are shown by *figs.* 13 to 18, Pl. XVI, the flooring fitted with cross-bearers, themselves protected by iron bands *m, m, m,* which are not as wide as the bearers. The cylinder laid longways, was steadied on each side by wooden wedges, fixed by spikes driven into each bearer, on each side of the iron band. These wedges getting unfastened; the cylinder become free, rolled against the stanchion, and exerted thereon a pressure, aggravated by the

floor of the waggon being inclined, owing to the load being all one side: the stanchion gave way.

156. *Loads projecting over the ends of the waggons.* a. *Danger of running off the line.* — Things, the length of which exceeds that of the waggon, but not enough to warrant the use of two vehicles, rails, planks, for example, may be the cause of a train running off the line, if they project too much, and if two or more waggons in the same condition are placed together. 20 feet rails are often loaded on shorter waggons 19 feet for example, and sometimes even on ballast waggons, which are only 16 feet long. If one of the loads happens to slip longitudinally, the ends of the rails interlock and the vehicles thus becoming consolidated into one, form a rigid system, incapable of passing through curves of sharp radius such as sidings.

In consequence of a train running off the line arising from such circumstances, the traffic department of the "Eastern" of France has interdicted the conveyance of rails, in waggons less than 18ft,70 long. If however, from want of waggons of this length, it is necessary to employ shorter ones, two of these waggons must never be put together. They should be separated, either by a waggon the load of which is shorter and cannot be reached by the ends of the rails projecting over the end of the waggon, or by an empty waggon, if needful.

The conveyance of rails was interdicted by a ministerial decision of the 28th. of May 1856, in trains containing passengers. It was only authorised in mixed trains, on those lines where the smallness of traffic did not warrant running regular goods-trains. A decree of the 27th. of June 1863 based on the absence of any new accident similar to that which had given rise to the interdiction, recalled this, and authorised in a general manner, the conveyance of rails in mixed trains, under the following conditions :

1. Loading the rails on platform-trucks, with sides sufficiently high to prevent them falling out; 2. Coupling on the rail-waggons immediately after the tender; 3. Their separation from the passenger-carriages, by one goods-waggon at least. But with the present length of rails, the first condition can be rarely carried out.

b. *Dangers to which porters are exposed.* — Projecting loads expose, besides, the porters to a danger, from which they would doubtless escape with attention; but one moment of negligence is sufficient for them to receive injuries frequently attended with fatal results; compelled, in order to couple the waggons, to place themselves beforehand between the buffers of the first waggon of the fixed portion of the train (145), and to wait holding

the link for the coming on of the waggons to be joined on; accustomed to rely on a space sufficient to protect them, they too often neglect to make sure that there is no part of the load projecting, and the foremen, on their side, too often neglect to warn them of such, above all when it is dark. It is desirable that formal written instructions should be addressed, on this subject to the staff, in case of accident in order that responsibility should be attached to some one, if there are grounds therefor. The men engaged in these operations are very often but little cognisant of the dangers attending the business; and it is of importance that those dangers should be pointed out to them by those over them. This is inculcated in the following terms on the "Eastern" of France system:

Station masters must be very careful to see that the loading of goods-waggons is done in such a manner as to allow nothing to project beyond the outside faces of the end cross pieces of the waggons. When the space between the waggons is incroached on by the load, the coupling and uncoupling of those waggons becomes very difficult for the men.

This mode of loading is, then, absolutely interdicted, so long as it is not rendered indispensable by the very nature of the loads, such as timber, iron, hay and straw. In this case, the station-masters must enter vehicles so loaded on the guard's way-bill. The guards must attend specially, during the whole journey, to the precautions to be taken, in order to avoid all accident during the shunting of these waggons.

5th. January 1865.

The sliding along of rails or long bars in general, can be avoided, as well as the danger their projecting causes to the porters, by employing for their conveyance waggons with fixed ends upon which the bars rest. If the whole load were supported on the same end, that would be subjected to too great a load and thrust, and moreover, the two pairs of springs would be very unequally loaded. The first drawback would be reduced, and the second would be avoided, by crossing the bars; but another would still always remain: the deformation of the frame, on account of the application of the loads at its ends. The longitudinals become convex. The buffers go slanting, and this deformation, independently of the injury it renders manifest in the vehicle, brings in a special cause of running off the line, by the difference of level of the buffers in contact.

This mode of employing waggons with ends is thus anything but satisfactory. It is the same thing with a contrivance which had solely for object the protection of the men while coupling. It consisted in employing platform trucks raising the load by means of cross-bearers laid on the trucks, deep enough to allow the men to pass freely under the projecting bars.

But in this way one of the drawbacks was only got rid of by aggravating an other. So raised thus, the load is much less stable and much more subject to be disturbed during running.

157. *Long pieces of timber.* — The conveyance of pieces of timber, which often attain very considerable lengths, is very easily done on common roads. The balks are simply loaded on the vehicle, or suspended by the middle to the axle of a truck with two large wheels. On railways either a special waggon supporting the balks towards their middle, with empty waggons joined on to prevent the loads fouling, or two waggons supporting the balks, and if the length of these is very considerable, with other waggons also joined on, to protect the projection of the load. Special waggons, with 6 or 8 wheels, can carry 20 to 22 tons of timber, in lengths from 65 to 72 feet; that is to say, as much as to weight and length as the two waggons coupled together. These are generally preferred, as they can be used also as ordinary platform trucks. They require besides, some special arrangements. The load must not rest directly on the waggons; which would in that case form an unyielding system of excessive length. The platforms are therefore provided at their middle, with a very strong cross piece which carries on it a turning cross-beam, held down to the first at the centre by a turning pin. The load is placed on the two turning cross-beams and kept in sideways, by iron stanchions, fitting into these beams. On the Upper Silesia line, these stanchions R, R (pl. XVII, *figs.* 1 to 4) are provided with racks, allowing the chains C, C, which fasten them, to be fixed at different heights, and which are tightened up by means of a lever T.

The two waggons are not connected together by means of the load, but by a coupling which although jointed, allows no longitudinal displacement of the load. When the timber traffic is sufficiently important to allow of special rolling stock for that purpose, the waggons being always coupled, have only elastic buffers and couplings at one end, or having nothing but dead buffers, S, S (pl. XVII, *figs.* 7 to 12).

The two platform trucks together, joined by a perch or pole, the length of which varies according to that of the timber, forms a sort of American waggon, with eight wheels : the load and the perch replacing the body and the frame. Each platform obeys the action of the rails on the flanges of its wheels, and its transverse axis takes the direction of the radii of the curves, provided that the cross-bearers can move round very freely. But this is not always the case. The cross-bearers having two rollers G, G, at each end, running on a ring of iron fixed on to the platform (Pl. XV, *fig.* 21) act

well, but the arrangement is somewhat complicated; and it is often considered sufficient to protect the movable cross-bearer, as well as the fixed one underneath, by bands of iron P, P, P, placed at the middle, and towards from the quarter of the length ends, and which carry the load (Central Swiss, Pl. XVII, *figs.* 19 and 21). But these iron bands are sometimes neglected to be examined, as to whether they are rusted enough to prevent sliding, which would be enough to cause the waggons to run off.

It is simpler and surer to bring the whole load round the pivot, surrounded by two large iron ferrules. The movable cross-beam T, tapered from the middle to the ends, can only rest on the fixed cross-beam towards the middle thereof; this form is besides in accordance with the conditions in which it works (Upper Silesia, Pl. XVII, *fig.* 1 to 6; Eastern of France, pl. XVII, *figs.* 7, 11 and 12).

The perch which, rigorously, would not be indispensable if the load were solidly fixed to the platforms, is without doubt an increase of security, but on condition of its being properly fastened. If not, it may itself be a cause of accident. On the 4th March 1869, a train on the line from *Paris to Marseilles* contained two waggons joined together, loaded with balks of timber 65 feet long. The perch, having separated from the first waggon, near *Chateauneuf* caught in the sleepers of the line and broke. The resistance which it caused to the second truck added to the resistance of the whole of the rest of the train, determined a complete separation between the trucks, and the balks fell out blocking up both lines.

The coupling of the perches is then an important detail; *figs.* 18 and 19, Pl. IX, represent the method first adopted on the "Méditerranée" system. An order of the Carriage and Waggon department, dated 13th april 1863, gave the following instructions on this point:

To couple on a perch between two waggons, several men lift up the perch, and hold it in a position very nearly horizontal; one of the hooks of the waggon is then inserted into the forked iron c, c' on the end of the perch, the pin B is then put against the eye of the fork, taking care that a stud on the pin coincides with a slot in the eye (this can only be done when the handle of the pin is turned up, as in BA' (*fig.* 18) then the pin B is pushed home through the hook, and through both eyes of the fork; the handle is then brought down into the position BA. (This last operation is indispensable, because it is in this position that the stud prevents the pin from coming out). Finally, the coupling is completed by passing the hooks of the guard-chains s, s, into the catches p, p, fixed at the end of the perch.

The same thing is done in coupling the other end of the perch to the second waggon.

If it be required to fix the perch sideways to the waggon, by means of the two catches fixed *ad hoc*, in the front cross-beams, the above process is also followed, excepting that

the body of the pin ought to be placed horizontally, so that the stud of the pin and the slot of the catch may coincide; when the pin is pushed home, it must then be turned down to prevent the pin coming out.

But experience has proved that this mode of coupling although seemingly well considered, was in reality very defective. The handle of the pin got shaken out of the vertical position, and the pin ended by coming out of the eye of the perch, which thus fell down. They were thus advised at the stations to fix the perch in its normal position by ropes, while the means of improving the coupling was being considered. A counterweight applied to the end of the pin-handle, would have probably sufficed to keep it in position. But a pin having a jointed end was adopted, which when the pin was in place, hung down, and kept the pin in. This is a simple and sure means, provided the joint pin does not wear nor rust. It was the breakage of this which caused the accident just now quoted; but that was the first since 1863, and it is easy to prevent its recurrence.

Supplementary waggons, added to keep clear the projections of overhanging loads, sometimes keep their stanchions. This is a mistake; the ends of the balks of timber, butting against these stanchions, may be the cause of breakages, and of the train running off the line. In consequence of an accident of this kind, the use of waggons with their stanchions fixed, has been formally prohibited on the "Méditerranée" system. It would be well if this prohibition were general.

A decision of the 14th Dec. 1857 has rendered applicable, in the case of long pieces of timber requiring the use of one or more waggons, the prohibition against rails, issued in the decision quoted above (155), of the 20th May 1856:

It is requisite, it says, to take, with respect to long pieces of timber, the same measures as for rails, in order to prevent the accidents of which these materials may be the cause.

The modification made in these measures has not been rendered as far as regards rails practicable, at least explicitly for pieces of timber. This difference may be explained by the dangers inherent to the perch; however the instructions of 1857 have only in view, those with regard to the loading itself, that is to say, the possibility of the fall of the balks of timber.

158. The concentration of the load on the middle of the platform-trucks, often requires strengthening to be added, without which the longitudinals

would hardly resist. As has been tried in Germany on the "South-North Junction" line, each longitudinal may be surmounted by a beam slightly cambered butting against two blocks bolted on to the longitudinals above the axle. The two beams composed of two rails fastened together and a piece of wood form two very flat stiff arcs, the thrust of which is taken by the longitudinals acting as ties, support the fixed and consequently the movable cross-bearers, which are constructed in a similar manner.

159. *Perches placed sideways, or under the frame; accidents which they may cause.* — All the platform trucks can take the supplementary framework, and be thus rapidly prepared for the conveyance of long timbers.

The speciality of waggons with a perch is besides not absolute. They can be disconnected, and appropriated independently to different freights, by so arranging the movable cross-beams, which ought never to be removed from them, in such a manner as not to compromise the stability of the loads. On the Upper Silesia line, the timber trucks, serve : 1. by taking away the movable cross-beam and its bolt, for the conveyance of machinery, agricultural implements, carriages, and so on; 2. by adding stanchions, for rails, planks, and so on; 3. by putting sides all round, for the conveyance of coal.

The perches are then placed, either laterally on supports *ad hoc* (Pl. XV, *fig.* 21); or under the frame (F, Pl. XVII, *figs.* 1 to 5). It is the same thing moreover, as regards one of the waggons, in the case of coupling two together, each of them having its perch, and one only being in place for coupling.

It is of consequence that the supports *s*, *s*, be solid, and that the perch should be well fixed thereon. Its fall caused by that of a support, or by the vibrations of tne truck, may be attended with consequences as serious as the fall of the coupled perch. If it leaves the waggon completely, or if it remains fixed thereto by its front end, so as to drag along the ground, that does not matter; but if it remains fixed by the farther end, it may catch in the sleepers, lift up and throw the waggon off the line.

Two occurrences of this kind took place, within a short interval, on the line from *Strasburg to Bale.* In the one case, the waggon, belonging to the *Central Swiss,* after being thrown off the line, ran a hundred yards entirely in the space between the two lines of rail. The train had just met the direct train from *Cologne to Bale,* so that by only a few minutes, the fall of the perch missed causing a catastrophe.

On the "Eastern" of France, the waggons with a perch are prepared for a maximum length of 72 feet; but longer balks are not excluded thereby. It

is only necessary to couple on a waggon, on the side where the balks project, or on both sides, if required. The distance between the waggons can even be lengthened at need, by inserting a platform truck between them, and or even if required two perches. But two perches should never be put directly end to end.

160. Waggons joined together but without perches are sometimes employed for pieces, the length of which is not considerable, but too long for one vehicle. Waggons with dead buffers are then preferable; they have no tendency to bring on the sliding along of the load; but besides the disadvantage of the rigidity of the system, this method is objectionable when it leads to a very unequal distribution of the load between the two axles of each waggon.

It was from this cause that a train ran off the line on the 17th Dec. 1868 at *Auxonne*. Armour-plates P, P, of the total weight of ten tons, had been placed thus in two waggons, partly crossing each other (Pl. XVII, *fig.* 22); the two intermediate axles being much more loaded than the end ones, the latter had therefore a tendency to lift under a slight shock, which is just what took place.

161. Loads of moderate length, but such however, as require the use of two waggons joined together, and composed of parts easily movable, may be dangerous when the precaution, simple enough no doubt, is omitted of preventing the longitudinal sliding of these parts, by binding ropes or better by chains, if the load presents sharp edges.

Negligence in this matter caused a deplorable accident on the "Northern" of France on the 7th July 1869.

A goods-train of fifty waggons running towards *Cambrai*, had towards the end, two platform trucks joined together, loaded with telegraph posts. As the load was not above the stanchions, it was not thought worth while to fasten it together, without considering that the distance between the stanchions was 18 feet and the length of the posts only 20 ft, 16; so that a slight amount of slipping would be enough to put them beyond the support of one stanchion. This is what took place.

One of the posts slipped down one of its ends, got free; it was unfortunately the front end, and on the side next the other line of rails. Near the station of *Cattinières*, the goods-train met a passenger-train. The projecting post scraped the tender, then the front brake-van, and one carriage, from which it tore off several door handles. The successive shocks having

increased the amount of its projection, it struck the carriage following, drove in the front panel a little above the seat, and struck in the back a passenger, who was thrown against the opposite side (it was a third class carriage), and had his head fractured. The post was broken, and the piece remained stuck in the panel.

We see here what consequences may be involved by negligence, slight in appearance, under the influence of a concurrence of fatal circumstances.

In Norway where the conveyance of planks is of great importance, the load is firmly secured by chains well tightened. The stock devoted to this freight, is provided with turning cross-beams T, T, which allow of its application, by joining with a perch, to the carriage of long balks (Pl. XV, *figs.* 15 to 18).

162. *Binding chains.* — The disadvantages of hemp ropes for fastening down loads of framed wood, or other carpentry, the sharp edges of which cut the ropes, determined the "Méditerranée" compagny some years ago (8th Sept. 1869) to substitute chains for ropes.

Each chain, with long links, is provided with a certain number of spare links, which in case of breakage, can be immediately substituted for the broken ones.

The cost of these fittings necessitates measures being taken to ensure their due return to those stations whence they are issued. The stamp of the company, and the number of the set are marked on the end hook.

§ V. Travelling cranes.

163. The conveyance of travelling cranes, which form a noticeable class of special vehicles, attached to the internal service of railways, requires precautions analogous to those adopted in the case of long balks of timber, but more particular.

These cranes differ : 1. in height; 2. in span; 3. in power. For certain types, apt to turn over on the side of the load, the limit of the power can only be attained, by fastening the machine down to the rails by screw clamps.

The "Méditerranée" system possesses 67 of these cranes, of a power from 1 ton,50 to 7 tons; and of which 17 cannot be coupled on to trains on account of the form and dimensions of their frames.

Lifting-screws, placed on the axle-boxes, put the springs out of action, when the crane is at work. These screws ought of course to be set free, so as to allow the bearing springs to act when the crane is attached to a train.

The clamps ought to be lifted up and firmly fixed to each other, or to the ends of the frame, by means of cords or special chains.

The crane is, moreover, placed between two waggons with falling ends (M). The ends next to the crane are let down; the crane is turned so that the jib and the counterpoise may be in the vertical plane of the axis of the line of rails, and they are kept in that position by the counterpoise frame being solidly attached to the platform underneath, or with the foundation of the crane itself. This fastening ought besides to make due allowance for the relative movements of the platforms when passing through curves.

The jib is then lowered, either by letting go the ties, or by taking them off altogether, and letting the jib rest on the auxiliary platform, by means of blocks of wood if required. The jib is besides fastened down to the platform by binding ropes, of course with the necessary play.

1. For the 7 tons type, represented by *fig.* 17, Pl. XVII, the counterpoise longitudinals of which L are solid with the frame, the counterpoise should be taken off and loaded on one of the auxiliary platforms.

2. The 7 tons crane shown by *fig.* 18, has the longitudinals jointed in O with the frame L, and suspension rods *t*, *t*, provided themselves with joints *a a'* at the middlle. To load this one, the counterpoise P, is pushed against the pivot, the longitudinals lifted by the bar or jack and rested on the platform, the joints *a a'* of the ties undone, and the longitudinals let down on the platform, wedging them up if required, in such a manner that they rest on their end, and as much as possible in the middle of the waggon. The counterpoise is then brought to the end of its travel, and fixed in that position.

For the conveyance of cranes, slow trains should be chosen, having the fewest possible operations to perform on the way, and to place the trio at the end, immediately in front of the hind brake-van.

If the train contains passenger-carriages, the crane ought to be separated therefrom by at least three waggons, the last platform of the *trio* included.

We have only to deal with travelling cranes as vehicles, and with reference to the condition of their conveyance by trains. We may however point out the arrangement proposed by the *Maubeuge* (Nord) iron works, to avoid a risk run with ordinary apparatuses, if the workmen having to load or unload a turn table for example, have forgotten to adjust the counterpoise. This one is automatic: it changes its place under the tension caused by the

load itself on the chain, which is attached to the counterpoise. It ought, for equilibrium, to displace itself horizontally, by a quantity proportional to the load, but it does not move, as in ordinary cranes upon straight and horizontal plates, its position of equilibrium corresponding to an element of an inclination, such that the component of the weight is equal to the tension of the chain : that is to say to the half of the load, abstraction made of the passive resistances.

§ VI. **Conveyance of matters of a dangerous nature.**

164. The official regulation of the 15th Nov. 1846, interdicts (art. 21) the admission into trains which carry passengers, of any matter capable of giving rise to either explosions or fire.

It adds :

Art. 66 : " Persons who may wish to send goods of the nature of those which are mentioned in art. 21 should declare them, at once, on bringing them into the stations. Precautionary measures will be prescribed, if there are grounds. "

The enumeration and classification of the matters to which special conditions are applied, have not yet been completety made out.

The question is in fact a delicate one. Care must be taken not to put impediments in the way of industry and commerce, unless urgently demanded for safety.

The rules actually in force have been fixed for gun-powder and munitions of war, by ministerial decrees of the 15th Feb , 4th May, and 15th June 1861, and 15th April 1863; and for the other materials reputed to be dangerous, by a decree of the 15th July 1863, which enlightened by experience, has modified the severity of the former decrees in certain respects.

Here are, first, the rules relating to powder :

1. Conformably to the clause 21 of the 15th Nov. 1846, it is prohibited to admit gun-powder, or powder for mining purposes, into passenger-trains, and into mixed trains. These materials can only be conveyed in goods trains containing no passenger-carriage.

2. Powder should always be delivered to the railway in double barrels. Mining powder, or that for sporting purposes are inclosed in a canvas bag, or in paper cartridges, and placed in a barrel, or in wooden case.

Prepared ammunition is placed in cases or barrels according to the des-

cription, the whole conformably to the mode in use for the ordinary transport of these munitions.

3. The barrels or cases of powder are loaded in covered and closed waggons, with closed-in panels, provided with buffing springs, and coupled up tight.

4. When a waggon is serving for the transport of powder, its flooring must be covered impermeably, so as to prevent any loss by spilling during the journey.

5. The use of waggons with brakes, is authorised only on condition: 1. that the brake shall not be used; 2. that the surfaces of the iron-work of the axes or levers of transmission, which might show, shall be carefully wrapped round with some fabric, or covered with wooden sockets.

6. The barrels must be laid down, and not stood on end in the waggons.

7. The load of a powder-waggon is limited to five tons, including the casks. The gross weight of one delivery is fixed at 10 waggons, or 50 tons, unless under peculiar circumstances. The measures to be taken will in that case be agreed on between the Departments of War, and of Publie Works.

165. *Matters other than gun-powder, mining and sporting powder.* — The decree of the 15th July 1863, concerning other matters than powder is thus drawn up:

First article. By application of art. 21 of the decree of the 15th November 1846, matters other than powder, which cannot be conveyed on railways, in trains containing passengers, are:

Fulminates,

Fulminating cotton.

Art. 2. Fireworks, caps, lucifer matches, phosphorus, ether, collodion, and other analogous substances not specified, will be equally excluded from trains containing passengers, on those lines of railway where there is a regular goods-service.

On the sections where regular goods-trains do not run, these substances may be carried in mixed trains.

Art. 3. Straw, hay, coal dust, acids and essences, charcoal, and all other substances more or less inflammable may be conveyed by all trains.

Art. 4. By the application of the art. 66 of the decree of the 15th November 1846 the conveyance of divers substances comprised in arts. 2 and 3 of present decree, is subjected to the following conditions:

Fireworks. Pieces of small dimension will be packed in cases of planks at least three eighths of an inch thick. Pieces of large dimensions will be fixed with care against the sides of the waggon, and isolated. No other material either explosive or easily inflammable, will be admitted into waggons containing fireworks.

Caps. Packed in bags, and the bags in cases of planks not less than three-eighths of an inch thick.

Lucifer matches. Careful packing in cases of planks not less than three-eighths of

an inch thick, and containing three cwt. at most. The cases of matches to be placed in waggons containing no other explosive or easily inflammable substance.

Phosphorus. Packing in vessels with strong sides, water tight, and full of water.

Ether, collodion, or other analogous substances, acids, essences. Packing in vessels or carboys with strong sides, and tight.

The other inflammable matters, which can be loaded on platform trucks, or in open waggons, must be covered carefully with tarpaulins.

ART. 5. Waggons containing explosive or inflammable materials, able to be conveyed by passenger-trains, will be in the last half of the train; they ought always to be preceded and followed by at least three waggons containing no explosive or easily inflammable matter.

ART. 6. The decrees of the 15th January 1861, and 15th April 1863, are not abrogated, concerning the conveyance of gun-powder and munitions of war, and equally applicable to mining and sporting powder.

ART. 7. The decrees of the 20th of August 1857 and 22nd March 1860, concerning the conveyance of phosphorus and lucifer matches, as well as our circulars of the 8th November 1858, 10th May and 21st May 1860 concerning the conveyance of caps and divers inflammable materials, are abrogated.

ART. 8. A revision will be proceeded with, of the provisions contrary to the present decree, contained in the model general tariffs, decreed on the 11th September 1861, and in our decree of the 30th May 1862, fixing the exceptional tariff anticipated by art. 47 of the railway companies' schedules of rules and regulations.

166. A decision of the 25th August 1868, special to the "Eastern" of France lines, had removed the condition of the use of tarpaulins imposed by the art. 4 above from charcoal in sacks. Another decision of the 4th of August 1869, has justly extended this exemption to all the railways.

The use of tarpaulins is besides still obligatory for charcoal otherwise despatched.

167. *New regulation.* — Matters other than powder have been the object of an attempt at more complete regulation, but which has not yet come to anything. It will be however, well to reproduce as a note, this project now old, but which by the way, is on the point of being put in execution.

§ 1. — CLASSIFICATION.

ARTICLE FIRST. Explosive or inflammable substances are classed, from the point of view of the precautions to be taken for their conveyance on railways, in four categories, namely :

1st *Category*. — Gun-powder, mining and sporting powder.

Munitions of war. — Fireworks.

Fulminates. — Fulminating cotton.

2nd *Category*. — Percussion caps. — Lucifer matches.

Chlorates. — Phosphorus. — Ether.

Collodion. — Sulphuret of carbon.

3rd *Category*. — Straw. — Hay. — Cotton. — Greasy rags. — Resins. — Essences and essential oils in casks not of metal. — Mineral oils in wooden casks or carboys not of metal.

4th *Category*. — Wood of every sort. — Charcoal. — Vegetable oils. — Mineral oils in metal vessels. — Alcohol. — Essences and essential oils in metal casks or carboys, and in general all matters more or less inflammable, not included in the three first categories.

The substances not designated will be successively introduced into this classification, and placed in the category which the risks inherent to their transport will assign them.

§ 2. — Packing and loading.

Art. 2. The instructions prescribed by the decrees of the 15th February 1861, and the 15th of April 1863, concerning the packing and loading of gun-powder, mining and sporting powder, are adhered to. These instructions are equally applicable to fulminates and fulminating cotton.

Concerning fireworks, pieces of small dimensions will be packed in cases of planks not less in thickness than three-eighths of an inch. Pieces of large dimensions will be fixed with care against the sides of the waggons, and isolated. No other easily explosive or inflammable matters will be admitted into waggons containing fireworks.

Art. 3. The conveyance of matters comprised in the 2nd category can be accepted only so far as their packing fulfils the following conditions :

Percussion caps. — Packing in sacks, and the sacks in cases of planks not less than three eighths of an inch in thickness.

Lucifer matches. — *Chlorates*. — Packing in cases of planks not less than three-eighths of an inch thick.

Phosphorus. — Packing in casks tight, and filled with water.

Ether. — *Collodion and sulphuret of carbon*. — Packing in vessels or carboys, with substantial sides, or covered with wicker or straw bands.

Every despatch of matters of the 2nd category ought to be in covered waggons, and with closed panels.

Art. 4. The matters of the third category are not subjected to any special condition, either as to packing or as to loading. At the same time, the despatch of essences, essential oils and mineral oils should not be undertaken unless the casks are solid, and do not present when received, any trace of leaking, and that the carboys not of metal, have a covering of willow, bands of straw or reeds, sufficient to protect them against shocks.

Straw, hay, and cotton, when conveyed in covered waggons ought to have covers put on so that the upper surface at least of the load might be covered. Greasy rags should be completely covered over.

Art. 5. The matters of the 4th category are not subjected to any special condition, either as to packing or loading.

§ 3. — Conveyance.

Art. 6. *Trains of every kind carrying passengers.* The conveyance of the matters comprised in the 1st category, cannot in any case, be effected by passengers trains.

The matters in the three last categories may be admitted into passenger trains, under the following conditions :

Waggons containing matters of the 2nd category ought to be separated from carriages containing passengers by at least three vehicles not containing matters easily inflammable, whether placed in front of, or behind the passenger-carriages.

Waggons containing matters of the 3rd category, ought to be separated from the carriages containing passengers, by at least three vehicles not containing matters easily inflammable, when they are placed in front of passenger carriages, and by one vehicle at least when they are placed behind.

Waggons containing matters of the 4th category ought to be separated from carriages containing passengers by one vehicle at least containing no matter easily inflammable.

Waggons containing matters of the 2nd and 3rd categories should be separated from the engine by at least two waggons, containing no matters easily inflammable.

When matters of the 3rd or of the 4th category are loaded in covered waggons, and with close panels, these waggons may occupy any position in the train.

Art. 7. The instructions of the preceding articles, concerning trains conveying passengers, are not applicable to goods-trains in which there are gendarmes, custom-house officers in charge, or drovers with castle.

Art. 8. *Ordinary goods-trains.* The place that waggons loaded with matters of the 1rst category should occupy in goods-trains remains fixed in conformity with the instructions given in the decrees of the 15th February 1861 and 15th April 1863.

Goods trains containing waggons loaded with these matters, may besides, be drawn, in the cases provided for by the regulations, by two engines placed one in front and the other behind, with the sole condition that the order for waggons loaded with powder, munitions of war, etc., always to be followed by three waggons at least, not containing powder or munitions of war, be duly acted upon.

The position in goods-trains of waggons loaded with matters of the three last categories, gives rise to no special order.

168. It is above all, the producers of matters either dangerous or considered so, who should urge the exaggeration of the dangers attributed thereto, and of the conditions imposed as to the conveyance thereof.

The "Chamber of Commerce" of *Birmingham* has given recently, as regards percussion caps, an example worthy of following. It has started trials tending to prove the harmlessness of the freight in bulk of fulminating matter thus divided into small fractions. Here is the most conclusive of these trials. Two cases each containing 50,000 caps, were placed on the line, and an engine with several goods-waggons run over them. The cases were broken, and the contents scattered all about, without any other effect

than some small partial explosions, quite harmless. This experiment will perhaps lead to a modification of the severe regulations to which the conveyance of caps is subjected.

169. *Mineral oils.* — Some accidents, notably in stations, and waggons while running catching fire, have inspired the companies with a distrust of crude petroleum, and analogous matters. This distrust has been shown by a demand for the approbation of tariffs, which profoundly alter the economical conditions of the carriage of the products in question.

Thus :

Are raised to the first series of general tariffs for slow goods :

1.	*Bituminous liquids*, in carboys, cases, cans or casks..	(heretofore in the 2nd series
2.	*Oil of tar*, in carboys, cases, cans, or casks........................ ...	d°
3.	*Oil of naphta*, in carboys, cases, cans, or casks.......................	d°
4.	*Coal oil* in casks... ...	d°
5.	*Petroleum oil*, in carboys, cases, cans or casks........................	d°
6.	*Schistous oil*, in carboys, cases, cans, or casks........................	d°
7.	*Luciline*, in carboys, cases, cans or casks.......................... ..	d°
8.	*Liquid boghead*, in metal casks, metal cases or carboys...............	3d
9.	*Liquid bituminous schists*..................	4th

Solid bituminous schists alone remain in the 4th series.

Moreover, a special tariff (P. V., No 37) of the " Méditerranée " system. from *Autun* to *Paris*, comprising : *bitumen* (*liquid*), *liquid coal-tar*, *liquid tar*, *oil of tar*, etc., is withdrawn.

Lastly, in another special tariff (P. V., n° 65), these articles are taken out : *liquid bitumen*, *liquid coaltar*, *essence of petroleum*, *liquid tar*, *oil of tar*, *naphta oil*, *petroleum oil*, *oil of schist*, *and luciline;* and the article : " oils not classed in casks ", is replaced therein by the article : " oils not classed in the *general tariff* in casks. "

These propositions confirmed by a ministerial decision of september 1869 have the effect of increasing, respectively, from 12,5, 37,5 and 50 per cent, the price of the conveyance of matters taken from the 2nd from the 3rd and from the 4th class to the first.

Now the special tariff 65 admitted all the mineral oils to the benefit of the rate of the 4th series.

It seems that this is not the way that guarantees should be sought against dangers, dreaded with reason besides. Rectified petroleum notably plays a part in industrial and domestic economy, of which it is impossible to foresee the importance. It is easily understood why the insurance companies raise their premiums enormously for the warehouses of the " Dock et Entrepôts" company of Marseilles, set apart for petroleum oils, and, also for the neigh-

bouring warehouses. This prohibitive measure has only for object to instigate the deplacement of the petroleum depôt. But monopoly has its obligations; and railways cannot in their own interest as well in the interest of all, reject a product of such general utility. They impose rigorous rules on the senders; the use of metal receptacles conveniently arranged, for example filling only partly, so as to prevent the effects of the great expansion of the oil, and so on. Nothing, in a word, is more just than that the conditions of this freight should be considered industrially. But let it be sought not to put things right which are by tariffs excessive, and more above all so little equitable. By making, in effect, all the mineral oils pass in mass from the 4th to the 1st series of the general tariffs, the new regulations include in them matters which are very far from presenting in the same degree the alleged danger, that is to say, that which results from the disengagement of vapors, easily inflammable. The decree of the 18th August 1866 laid down in this respect the bases of a distinction and appreciation, which it would not without doubt have been very difficult to convert into perfectly practical rules.

§ VII. — **Putrescent matters.**

170. This point has been touched upon by a ministerial circular of the 18th August 1868 :

" The custom " it says " seems to have been introduced, on certain lines of railway, to join on to mixed passenger-trains and to goods-trains carrying passengers, and of which the composition is provided for by article 18 of the rule of the 15th November 1846, waggons loaded with animal charcoal, casks of blood, raw leather, or any other matters exhaling a putrid odour. This kind of freight is the source of legitimate complaints from the passengers. In consequence, I have the honour to inform you, that in future, all transport of putrescent matters, the depôt of which, in the terms of the regulation, would form an objectionable or unwholesome establishment, must be interdicted in trains of every kind containing passengers. An exception to this measure will only be admitted for lines, the importance of the traffic of which, does not warrant special goods-trains; and in this case the companies must submit to the Railway Department propositions for determining the number and position in the train, of waggons containing these matters. "

These instructions justify themselves. They reconcile the requirements of security and health, with the legitimate interests of industry. The same with regard to the instructions, which have authorised two companies to receive raw intestines only in casks hermetically closed, and perfectly

tight, and only with the express order of the sender, to deliver on, after arrival, to their destination.

It is to this class of putrescent matters, that the products of emptying cesspools belong, the economical carriage of which by railways would render a real service to agriculture. A manufacturer has tried to organise this freight on the "Eastern" of France, setting apart therefore waggons which turn their contents directly into special reservoirs. But they have not succeeded in completely avoiding the drawbacks of such a proximity, and besides the matters in question can with difficulty bear the expense of the carriage, and of the special and costly arrangements which they require.

It is a different thing with matters of greater value, and which do not belong besides to the putrescent class, but to that of dangerous matters, such as tar. The *Anzin* company, for example, brings from a great number of works the tar which is employed in the manufacture of block fuel, and employs for this conveyance waggons with sheet-iron tanks belonging to itself, and which let the tar run into large reservoirs. Leakages running down on to the permanent way may cause a train to catch fire; it is important then that the tank waggons should close very hermetically.

§ VIII. — **Weights and loads.**

171. These are the tares and loads of the different types of waggons of the "Méditerranée" system:

	TARE.	MAXIMUM load.	DEAD WEIGHT per ton of useful load.
	tons	tons	tons
1. Platforms (L, Lf and M, Mf)	3,00	5,00	0,67
	to 5,20	10,00	0,51
2. Maringottes (P, PP, 4, 6, and 8 wh.)	3,00	5,00	0,60
	to 6,12	20,00	0,30
3. Open waggons (K, Kf)	3,30	5,00	0,67
	to 5,20	10,00	0,52
4. Coal waggons (S, Sf, and T, Tf)	3,30	5,00	0,67
	to 5,36	10,00	0,53
5. Coke waggons (U and Uf)	4,10	8,00	0,51
	to 5,40	10,00	0,54
6. Cattle waggons (J and Jf)	4,80	8,00	0,60
	to 7,00	8,00	0,87
7. Covered waggons (H and Hf)	3,90	8,00	0,49
	to 5,80	8,00	0,72

For weighted brake-waggons the tare is raised to 9 tons, but the load is reduced to 4 tons.

The open iron truck of MM. *Schmidt* (147) weighs 5 tns, 10; its normal load is 10 tons.

We may remark in passing that the weights of matters which take up water and are carried open, may vary notably under atmospheric influences. The increase is often from 3 to 4 per cent for coke, and coal, and may even attain to double that between the extreme limits of dry and damp. Anthracite was also carried open until lately. In consequence of recent judicial decisions, the "Méditerranée" company is under the necessity of now working this freight in waggons provided with tarpaulins, and these get rapidly destroyed. This motive has induced the company to demand authority to take out anthracite from the list of slow speed goods, by which the senders and receivers can themselves do the loading and unloading. But that is only an indirect way of indemnifying themselves, and it would seem more natural to make the freight itself pay, by a suitable tariff for the special precautions which it requires.

The platform-truck for planks, of the Norwegian lines (Pl. XV, *figs.* 17 to 20) weighs 3 tons, 07, and carries from 5 to 6 tons according as the wood is more or less dry. The dead weight per ton of useful load varies then from 0 ton, 61 to 0 ton, 51.

172. The traffic-department instructions are, naturally, to utilise the rolling-stock as completely as possible; but attention must be given to avoid that tendency becoming an abuse, that is to say, dangerous overloading. The inscription on each waggon of the limit of its load should prevent all errors. The station-masters should attentively verify the weights of the loads and not forget that in case of accidents imputable to an excessive load, they will be held personally responsible.

173. Considered in themselves the preceding figures (171) give only a most inefficient idea of the real importance of dead-weight in relation to useful load. The waggons run very often with incomplete loads and even altogether empty. It is rare that the activity of the traffic is the same in both directions and the disproportion is often enormous. For example, the trains which arrive full at *Paris* frequently go away thence empty, because, centre of an enormous consumption, that large city furnishes only from all its branches of industry, an incomparably less tonnage. The companies seek to avoid those empty returns by great reductions in the tariff, which allows,

of carrying for considerable distances, from *Paris* to *Bordeaux* for example, materials of small value, such as plaster. But these low tariffs connot be looked upon as normal prices remunerative in themselves. If they are possible, it is that in reality, the one way pays the other. The ratio of the dead-weight to the useful load is more unfavourable still, if as ought to be, the weight of the locomotive is included in the first; the disproportion becomes especially great on lines with steep gradients the weight of the engine being a constant which is divided over a number of waggons the more reduced the stiffer the incline.

The reduction of the dead-weight of goods-stock should be of most special importance on lines of large traffic, or, which is not always the same, with a great multiplicity of trains. The line has then to be *swept* clear; thus, it is not out of generosity that the speed of goods-trains is often on English railways 25 and 30 miles an hour. The gross weights of the trains have to be reduced in consequence, and the ratio of the useful load to the *total* dead-weight, that is to say, engine included, is then most unfavourable.

A writer who has left a certain reputation due more perhaps to his faults than to his merits *Proudhon*, has set forth in a book entitled : *Reforms to be made in the working of railways* (*), his ideas on the economical conditions of this great branch of industry. Justly struck by the increase of dead-weight, but naively believing that the fact was as new to every one else as it was to himself, and that he had discovered the evil, he imagined that he had also discovered the remedy.

This remedy consists more especially in reducing to 5 or 6 miles an hour, at the most, the speed of goods-trains.

" Could any thing " he says, page 278, " more absurd be imagined, than to carry " coal, ashlar, minerals, plaster, stones at 13, 14, 17 miles an hour, a speed which was " never attained by the steeds of *Louis XIV* in all his glory... and then, that commerce " would consent to pay dearer for such conveyance, simply for the beauty of steam " transport. "

Not content with thus reducing the speed of goods-trains, the author would only let them run at night, "Goods being" says he, "always sure to arrive soon enough. "

Does he accept the direct consequence of this *progress*, that is to say the necessity of doubling, of trebling the line, on the railways of great traffic?

Very far from it and it is here that burst out the greatness and unfore-

(*) Published without the author's name. — *Garnier, Paris*, 1855.

seen effects of the discovery: the two thirds of our railways will then want no more than one single line!

" (Page 222): We do not wish to exaggerate anything; we do not pretend that on
" lines like those from *Paris* to *Rouen*, *Orleans*, *Amiens* and *Lyons* to *Saint Etienne*,
" that a double line is too much for the service of passengers and goods. But we
" maintain that on the two thirds of the French railways with the system of reform
" that we are proposing a single line is sufficient and that the construction of a second
" line only proves the incapacity of those working them. "

Would any one believe that these lines were made public scarcely fourteen years since? Such are the errors into which a public writer allows himself to stray, a writer often quoted as a model of rigid logic, when he thinks proper to apply to a subject which he has not taken the trouble to study, his system of slashing assertions, and the processes of his discussion, the emptyness and futility of which are so little dissimulated by a grand show of figures, in all appearance laboriously collected and collated.

The relative dead-weight of goods-stock is much more considerable in the United States than in Europe, the bodies, always carried on two four-wheeled bogey-trucks, having dimensions greatly inferior to those of passenger-bodies; their length does not exceed 30 feet, and their breadth 8ft,50. Their weight varies from 9 to 11 tons, and that of the load from 9 to 12 tons. The ratio is then 1, very nearly.

CHAPTER IV.

MEANS OF ADAPTING CARRYING-STOCK TO RUN THROUGH CURVES.

§ I. — Modifications made in rigid stock.

174. If even main lines can be laid down with curves large enough for the conditions of running through them to be the same as on straight lines, sharper curves are indispensable for crossings, so numerous on important stations.

We have to examine :

1. The modifications which can be made in the stock called : *rigid,* without depriving it of its essential character, so as to enable it to run in the curves in question ;

2. The particular arrangements to which recourse is had, when the curves to be run through are looked upon, rightly or wrongly, as too stiff for stock built under ordinary conditions.

The first point reduces itself to very little, as long as it is a question only, as now, of describing the expedients applied, and not to appreciate their real influence on the resistance in a curve of a given radius.

As to the second, which has exercised the talents of many inventors, we shall not treat it with the developments it at first would seem to require. Experience has, in effect, greatly lessened its apparent importance; the problem of the free running of vehicles on a curve is one of those, the geometrical solution of which is of little practical utility, because it puts on an equal footing, conditions which are far from being equally absolute and equally important.

It is unnecessary to say besides, that the locomotive, which also is itself a vehicle, ought equally to be studied with reference to curves. We reserve this question so as not to divide the study of railway motors. Let us only remember, from now, that the locomotive, because of the intricate peculiarities of its construction, yields with a great deal more difficulty than carrying-stock, either to the application of simple palliatives, which diminish the rigidity of the vehicle, or to the fundamental arrangements proper for giving it absolute flexibility. Such is especially the motive which diminishes the

importance of the solution of the problem, restricted to carriages and waggons. To solve it for these (if it as much as exists in what concerns them, unless in some extreme cases), and for these only, is in reality to do nothing, as long as the locomotive exists with the requirements peculiar to it.

175. There is more : a complete geometrical solution including locomotives, would not have all the bearing attributed to it at first sight. If we succeeded in constituting a rolling stock, waggons, and motor, capable of running easily in curves of a very small radius (100 yards for example, to name a figure), and that without sacrificing, besides, any of the conditions that the locomotive ought to fulfil; if even this stock were simple, solid; not costly in maintenance; if even it were to run through these curves freely, that is to say, without increase over the resistance developed on a straight line, we should not have thereby altered the future conditions of the establishment of great lines; we should not have freed it from the burthens so often entailed on it by the nature of the ground; we should not have reduced our principal arteries, laid down at such great cost with their curves of larges radius, to the state of superannuated specimens of an art in its infancy. We should have rendered unquestionably a great service to the economical construction and working of certain subsidiary lines in isolated positions; but for the great lines the situation would be but little modified.

The necessity of admitting curves of small radius cannot always be avoided. The line from *Vienna* to *Trieste* by the Semmering, for example, is in this case. The curves are there as low as 200 yards. But these are, so to speak, particular points, where a necessary evil is accepted. Within these limits besides ordinary stock answers, not without a notable increase of resistance, it is true, but without danger. As carrying stock ought to run everywhere, on sections with large curves, passed over at high speeds, as well as on sections with sharp curves, run over at low speeds, it is quite simple that it should be constructed with reference to its normal conditions and not for exceptional sections. Provided that it passes through, even with a certain amount of constraint, that is sufficient.

There is besides a condition which overrules all, that of security, and on lines of great traffic and high speed, this condition alone is sufficient to exclude, even at the price of great sacrifices and unless there is absolute impossibility, very sharp and numerous curves. On such lines in fact, the greatest danger is that of collisions. If, theoretically, on paper, system of signals can keep every thing right and good, it is not so in practice. No-

thing can come up to the engine driver assuring himself by his own direct view along straight lines and curves of large radius, that the line before him is free, and that he may run on with full confidence. As to the objection raised with reference to fog, it is without weight, because it affects equally the two terms of comparison; if it hinders the driver from seeing the obstacles, it prevents him equally from seeing the signal. Fog is a real difficulty, without doubt, common to all cases; but it is happily, an exception.

The question which occupies us has only then, generally, as regards carriages and waggons, a secondary interest. As to engines, that is another matter.

As they can be changed at will, it is quite natural to devote special types to the sections, the laying out of which presents special conditions. The adaptation of vehicles to curves of small radius, would be of unquestionable utility for locomotives. It is only for them that the question is of real importance, and only also for them that the solution is difficult. It is thus quite understood, that in occupying ourselves, just now, with carrying-stock alone, we shall be dealing with the small side of the question; and it must be taken up again on the subject of engines.

176. Let there be a vehicle with parallel axles, and the distance apart thereof d; let us seek the necessary conditions to enable it to run in a curve of a radius ρ.

If it were only a question of placing the four flanges exactly between the rails, the condition has been set forth (I. 199) it is: $\frac{2}{j}\left(2rm + d\sqrt{2rm}\right) = \rho$, j being the total play in the road, r the mean radius of the wheels, m the projection of the flange.

But this condition disappears as soon as the first of the three following conditions of the free movement in a curve is fulfilled:

1. Radial position of the axles;

2. Transformation of each pair of wheels into a rolling cone, with its summit at the centre of the curve;

3. Production of a centripetal force equal to the centrifugal force, and that independent of all reaction of the exterior rail on the flanges.

1. *Radial position of the axles.* It is evidently sufficient to satisfy the first condition, to give the axle-box a total play in the guard plates $2\delta = \frac{de}{2\rho}$, e being the breadth of the road from axis to axis of the rails (4 ft, 8 ins $\frac{1}{2}$).

For $\rho = 492$ ft, $d = 11$ ft,81, we have $\delta = 0$ in,35.

A play of 0 in,35 from one side to the other of the mean position, does not sensibly alter the parallelism of the axles. We may even say that it insures that on a straight line, because it can compensate, at need, for a slight fault in fitting.

It is not besides likely to produce knocking of the boxes against the plates, the amount of play being too small for the first to strike against the second with a notable relative speed. And from this point of view, the play can be much greater, when the load is transmitted to the spring and then to the box, by inclined hangers, which oppose the oscillations of the axle.

For six-wheeled vehicles, the only additional condition, is evidently a longitudinal play of the middle axle, a play equal to double the versed sine of the arc having for chord the distance apart d. Without this centrifugal displacement of the intermediate axle, the flange of the inside wheel would tend to mount on to its rail, and moreover, the conic'ty would act in a contrary direction, this wheel running on its maximum circumference, and the one opposite on a circumference smaller than the mean radius.

This play is : $f = \frac{d^2}{8\rho}$ neglecting f against 2ρ :

For $d = 11$ ft,81, $\rho' = 426$ ft, $f = 0$ in,39. It is then of the same order as the preceding one; and is attended with no more disadvantages. For carriages with axles a great distance apart, it can be pushed farther. This displacement of the middle axle is facilitated by the smaller inclination of the spring hangers (μ, μ, Pl. V, *fig.* 12), and often by a special joint, such as the addition of a ring (pl. VI, *fig.* 7; pl. XI, fig. 18).

Such slight play, transversal for the end axles, longitudinal for the middle axle, suffices for a vehicle that is considered as already inscribed in the curve. It is not the same thing if we consider what passes at the moment when the vehicle passes from the straight line on to the curve, or *vice-versâ*. If it is solidly fixed to the frame, transversally to the line, the outside axle cannot undergo the centripetal deviation which accompanies its change of direction, without drawing into this movement the whole vehicle, which pivots round the vertical passing through its centre of gravity. The entrance into a curve is then very sudden, at any rate, if the radius be small and the speed considerable. This drawback disappears if this axle possesses, besides the convergent play, a certain longitudinal play. The pair of wheels alone undergoes then an instantaneous deviation under the vehicle, which, itself is only gradually deviated, so to speak, leisurely, and consequently without shock.

177. 2. *Suppression of sliding at the tyres.* — The transformation of the pair of wheels into a rolling cone, is effected at the passage from the tangent to the curve, by the combined action of inertia, on the one part, of the conicity and the play in the road, on the other. The rails displace transversally under the pair of wheels, which continues at first its rectilinear movement, the outside rail approaches the flange of the wheel which it supports, and the inside rail leaves the flange of its wheel. The axle free, thanks to the transversal play (and if besides the centrifugal force is destroyed), takes rapidly a radial position, and the condition of the coincidence of the summit of the rolling cone with the centre of curvature is evidently : $\frac{eir}{j} = \rho$, $\frac{1}{i}$ being the conicity, or sine of the inclination of the cone : for $i = 20$, $r = 1$ ft, 64, $e = 4$ ft, 92, $j = 0$, in, 94, that is to say, for the values of the conicity and of the play of the road allowed on straight lines, we have : $\rho = 683$ yards.

The limit which results from those values is then too high. It can be reduced by increasing either j (I, 199, 200) or $\frac{1}{i}$ and at need, both of them.

If as we have seen (I, 199) the effective play is, with an equal distance apart of the rails, less on a curve than on a straight line, on the hypothesis of the absolute parallelism of the axles; this play remains the same, when the convergence of the axles places the flanges tangentially to the rails. If then the rails on a curve are gradually put farther apart (I, 199) the conicity profits by the total play. For an increase in the distance a part of 0 in, 94, for example, quite compatible with the usual width of the tyre, the radius limit is reduced to one half or 341 yards.

Less radii being often necessary, even on main lines, we must either increase also $\frac{1}{i}$ or give up adhering rigorously to the condition $\frac{eir}{j} = \rho$, that is to say to accept a small sliding of the tyres with the consequences thereof, as well as a somewhat greater resistance and wear of the tyres and the rails, and more frequent torsion of the axle than on a straight line.

This is what is ordinarily done, always so as not to sacrifice running on the straight to running through curves of small radius, that is to say the normal position to the exceptional one.

Bi-conical tyres. Contrivances, specious at first sight, has been proposed and applied. It consists in forming the tyre, of two truncated cones of unequal inclinations; the least towards the flange, the greater to the outside. In curves of moderate radii and in which consequently the distance apart

of the rails is nothing, or very small, the outside cone is never run on. This only acts on the sharpest curves where the extra play in the road is at its maximum and the difference of the radii is then increased. This contrivance is not equivalent however to the complete substitution of the greatest amount of conicity for the least, because the lessening of the inclination only affects one wheel, that which runs on the internal radius.

Nothing prevents the two elements being brought into harmony : the conicity, and the inclination of the rail, by giving the inside rail on the sharpest curves, an inclination equal to that of the outside cone. But in practice, this has been dispensed with as a complication of the junction of the two inclinations. These results therefrom, that the tyres running on rails with an inclination less than their own conicity, bear not on the middle of the rail, but on the overhanging flange.

This compound profile has been applied :

1. On the line from *Orawytza* to *Steierdorf* (Banat) which presents numerous curves of 124 yards. The tyres were 5 inches broad, of which 1 in, 18 was for the flange, 1 in, 97 at an inclination of $\frac{1}{10}$, 1 in, 85 at an inclination of $\frac{1}{7}$.

2. On the great line from *Salzbourg* to *Vienna*, the engineers rejected, as we have seen (I, 56) the conicity on the straight lines, and on curves of large radius, but did not however do so in the case of sharp curves also, the radii of which are as low as 310 yards. Thereon, tyres cylindrical towards the flange for two-thirds of the width of the tyres, and inclined at $\frac{1}{12}$ towards the outside. But without going back on the question, judged of by this appeal to experiment on a large scale, of the utility of a slight conicity, the idea of the compound tyre is now condemned, as more taking at first sight, than really practical; it renders, without much utility, the maintenance of the tyres troublesome and costly.

178. *Action of the conicity in a contrary direction for the hind axle.* — It has been long remarked that conicity, indisputable when the question is only of a single axle, or of two or more axles able to converge towards the centre of the curve, is ineffective for a system with two axles parallel, or with an insufficient amount of convergence. On a curve, this system tends first, because of the manner in which every part is bound together, to place itself obliquely to the line (Pl. III, *fig.* 14), that is to say, so that the longitudinal axis of the vehicle is not normal to the radius of curvature passing through the centre of the figure, and the flange of the outside front wheel grinds, so to say, into its rail. For this first pair of wheels, the conicity

acts in a suitable direction; but it is the contrary for the second pair, the obliquity of the system bringing the inside wheel up against its rail, and drawing the outside wheel apart from its rail; in such a manner as that the conicity, in this case, acts in the reverse way. But that would not be taken as an objection against conicity in the way that it is applied. The effect indicated is only produced at the entrance on to a curve; it ceases, if the convergence is sufficient, as soon as the axles have taken the relative suitable position, and if the convergence is insufficient, there is another remedy: that is, a slight longitudinal play of the axles which permits them to take transversally to the rails, the suitable position for the normal action of the conicity.

179. 3. *Neutralising the centrifugal force.* — It is as we have seen (I, 200), the permanent way itself and not the rolling stock, which has the task of creating centripetal force, where that is necessary.

Conicity really itself, as has been already pointed out (I, 199), gives rise to a centripetal force due to the non-symmetry of the reactions of the two rails, supposed at the same level, on the pair of wheels transformed into a rolling cone. If we express that the pair of wheels and the corresponding half of the vehicle are in equilibrium transversally to the line, on a curve with radius ρ, under the influence: 1. of the reactions of the two rails; 2. of the half weight P of the system; and 3. of a centrifugal force F, applied at its centre of gravity at the height h above the rails, we easily find for the values of the force F, and of its equal, the centripetal force due to the conicity, the transverse friction of the wheels on the rails being at the same time neglected:

$$F = P\frac{j}{ei}\frac{2ei^2 - 2h\sqrt{i^2-1}}{ei^2 - 2h\sqrt{i^2-1}}:$$

As $F = \frac{P}{g}\frac{V^2}{\rho}$, the speed for which the centrifugal force is destroyed is, neglecting 1 against i^2,

$$V = \sqrt{g\rho \cdot \frac{j}{ei}\frac{2ei-2h}{ei-2h}},$$

and replacing ρ by its value $\frac{eir}{j}$ which suppresses the sliding at the tyres (177), we have for the speed at which the system runs *freely* through the curve:

$$V = \sqrt{gr\frac{2ei-2h}{ei-2h}};$$

For

$$e = 4\text{ ft}, 92,\ i = 20,\ r = 1\text{ ft}, 64,\ h = 4\text{ ft}, 92, \text{ we have: } V = 10\text{ ft}, 50.$$

The speed for which the centripetal force due to the conicity would be in equilibrium with the centrifugal force, on the curve-limit, with a radius by the way much too large, passed through without sliding at the tyres, is thus altogether insufficient. But as we have seen, this is no disadvantage; and in practice the raising of the rail does not even take into account this slight centripetal force, arising from the conicity, any more than of the transverse friction.

§ II. — Solutions appliable to stock with a great distance between the axles, or having to run through very sharp curves.

180. M. *Laignel's expedient.* — This well known expedient, consists in making, on curves, the outside wheel bear on its flange, which runs on the rail widened out for that purpose towards the inside of the line. The pair of wheels is thereby transformed into a rolling-cone, just as it would be by a very considerable amount of conicity. But this cone is always the same, independent of the radius of the curve, which amounts to saying, that this radius itself should be invariable. The radius of the curve run through without sliding, is evidently :

$$\rho = \frac{re}{m} \quad \text{for} \quad r = 1\text{ ft}, 64 \mid m = 1\text{ in}, 18 \mid e = 4\text{ ft}, 92,\ \rho = 82 \text{ feet}.$$

The aim is thus overpassed.

It would be requisite besides, r not being constant (it is not the same in engines as in carrying-stock), that m should vary also, which it does not and cannot do.

In order to render his idea appliable even to great lines, M. *Laignel* proposed: 1. to give the tyres the ordinary conicity of $\frac{1}{20}$, sufficient for curves of about 650 yards (177) 2. for sharper curves, but however, of radius still much superior to 82 ft, to substitute for the circular arc, a polygon inscribed within that arc, joining the sides thereof by small arcs of 82 feet radius : a solution altogether inadmissible : 1. because we must keep from multiplying curves unnecessarily as they involve a special resistance independently of their length : the resistance on entering and leaving; 2. because the expedient is incomplete; it eliminates the sliding of the tyres, but does nothing for the convergence, which in such sharp curves would be indispensable with the ordinary distances apart of axles.

What has been called, a little ambitiously, the *Laignel* system, has its value, certainly. But its application is necessarily restricted to little industrial lines, which can often be established at a small cost, thanks to the sharp bends with which they can be laid out, and the axles of the rolling-stock of which are at a very short distance apart, which renders the want of convergence bearable on curves of very small radius. M. *Laignel* only obviates the consequences of the inequality of the running of the two wheels and this end is more simply attained by doing away with their absolute solidarity. Not that it would do to return to fixed axles with loose wheels; but the axles movable with one wheel only keyed-on, reconciles everything. Usually, the whole system turns with one common movement, and the relative angular displacement of the two axles only comes in when necessary. This arrangement is that of the new lorries of the internal conveyance, in the mines of *Anzin*, and its principle is also quite applicable to daylight rolling-stock.

181. *American rolling-stock.* — Its character as regards running through curves, has been defined farther back (14). The transverse axis of each of the groups of parallel axles takes freely the radial position, and the axles are near enough together to make only a very small angle with the radius passing through the centre of the bogey-truck. As to the sliding of the tyres, it is eliminated or diminished by the conicity, carried, if need be, to an excessive degree. Of all the arrangements tried, this is the only one which has really succeeded. It is efficient, it is simple, and lastly it is necessary (or some other equivalent in place of it) for the great lengths of carriages imposed by the conditions under which American rolling-stock is constituted (14).

182. The importance of the convergence of the axles was formerly greatly exaggerated, and it was tried to be realised even under conditions of radius of curves, and distance between the axles, which rendered it perfectly unnecessary. It would be superfluous to return now to these solutions of difficulties, purely imaginary, if they were not often found to reappear as novelties and with pretensions so much less founded on utility, as if it had been formerly permitted to delude oneself as to their value, it is no longer the same thing now-a-days.

In the American stock, the articulated trucks are kept on the rails, by the flanges of the four wheels, which are solidly fixed together.

It has been tried under different forms, to apply the articulation to each axle separately.

I saw more than sixteen years ago on the Upper Italy line four-wheeled waggons, in this way supported by two articulated trucks, each with one single axle; the two trucks, each supporting the body by means of four small conical rollers, were attached to each other by crossed rods; in consequence of that connection, the one axle could not incline itself to the longitudinal axis of the vehicle, without the other inclining itself, in the same degree, in the contrary direction; the two tie-rods maintained besides, the parallelism, as long as the action of the flanges did not induce the axles to go therefrom, that is to say, on a straight line.

An analogous arrangement has been applied to some of the four-wheeled waggons of the *Staat's Bahn* (Austria). In this, recourse was had to a peculiar contrivance in order to insure the small supporting rollers revolving, as they often ceased to act, and got out of order; each of these rollers had, added to it, a toothed crown in gear with a small circular rack; the partial frame could not then turn relatively to the principal frame, without the rollers themselves turning also round their axles.

183. *Riener's system.* — M. *Riener*, an Austrian engineer proposed as far back as 1854, a solution answering theoretically, which was applied two years afterwards to several passenger-carriages of the South Austrian line. If a vehicle be considered as successively on a straight line and on a curve (Pl. III, *fig.* 12), it will be seen that the axle which occupies in the straight line the position $a\ b$, ought to take, in a curve, the position $a'\ b'$. In order to pass from the first to the second, it has to: 1. slide longitudinally from $o\ o'$; 2. turn round its centre o, through the angle α.

The movement of translation is produced by the action of the outside rail on the flange, without the mass of the vehicle being immediately involved in this deviation, provided that the axle has sufficient play in that direction. In order that the angular movement may act at the same time, it is sufficient that the axle be directed, not by surfaces normal to the longitudinal axis of the vehicle, but by guides conveniently inclined to that axis. The axle may move, either within the axle-box, fixed, or may draw the box along with it, and consequently the spring, in its movement. The springs ought thus to have long hangers, which yield to the displacements of the axle, by making a slight inclination with the vertical, sufficient to bring and keep the axle in the mean position, on a straight line.

The guides may be either plane surfaces or cylindrical surfaces circular in section, having on the two sides of the vehicle, either two axes symmetrically placed, or the same axis. In the last case, the axle makes, in all posi-

tions, the same angle with the horizontal element of the straight section, which is not so in the others. *Figs* 1 to 9 of plate XII represent the boxes of *Riener's* system applied to a carriage with six wheels, of the South-Austrian-Lombardy lines. They are movable, and with plain guides. The springs fixed on these boxes, receive the load from the frame by means of double supports, very long, *s*, *s* (Pl. XI, *figs*. 26 to 28), between which are placed two long hangers *m*, *m*, united by the articulations *o*, *k*, on one side with the supports, on the other with the springs. On a straight line the hangers *m*, *m* are vertical; on a curve the two articulations *o*, *k*, yield to the two movements of the spring relatively to the frame; the inclination of the hangers to the vertical tends to bring back the axle to its mean position, as soon as the action of the flanges of the wheels ceases to move it therefrom.

It would be superfluous to insist further at the present day, on an arrangement, the principle of which was applied anew some years ago, by M. *Roy*, who combined with it the independence of the wheels. In the conditions under which it was desired to apply it, it had against it one decisive objection which dispenses with all discussion on it: It was unnecessary.

As to the extreme cases, in which there might be some reason for it, it seems inferior to others, which we shall point out by and by (186 and following).

184. *Articulated system*. — The articulated system made a great deal of noise; it has had, thanks to the perseverance of M. *Arnoux*, the good fortune of getting applied on a large scale close to *Paris*. It has succeeded this extent, that experiment has confirmed the views of the inventor, without bringing out any unforeseen drawback. But it has failed in reality, seeing that its application, made on the *Sceaux* line, is and will probably remain unique, at least on railways in their complete state of development.

This apparent contradiction is easily explained. M. *Arnoux* cannot assuredly be accused of having pursued a futile end; the inflictions which the necessity of curves of large radius imposes on the establishment of railways, has been too often and too justly insisted on, for the importance of a discovery, which would deliver them therefrom when required, to be put in doubt. But on the one part, the solution, here again is incomplete. It does not apply to the engine, which really however demands it urgently, all the more that curves of small radius seldom exist without steep gradients; and locomotives of great tractive power and low speed, rebel still

more than the others against the application of expedients for giving them flexibility.

On the other hand, the articulated system has like that of M. *Laignel*, aimed at too much. It was the question, with him, of effecting a revolution in the conditions of establishing railways; but lines of great traffic and with trains at high speeds ought to accept the conditions which result from the very object itself which they serve, because they can support them. Completed by the appropriation of the locomotive, the articulated system would have been suitable in certain special and modest cases. But to dream of its more general application was to incur inevitable deception; the curves of sharpness undue, which alone could to a certain point form grounds for this application being, of themselves, necessarily excluded from important lines.

At the same time that we reduce to its true value the system in question, we must not underrate what it possesses of plausibility and ingenuity, and a summary description of it ought to find a place in this work.

M. *Arnoux* was guided in his conception by ordinary road vehicles, of which he had a long experience. The bases of the system are :

1° The independence of the wheels, movable on the axles, which are fixed; this does away at once with the conicity and consequently the tilt of the rail;

2° The movability of the axles round a turning pin, a movability which allows them always to place themselves normally to the line.

3° The obligation, for the axles, to take this position (only a little prematurely at the points where the radius of curvature changes) by the fact of an arrangement which is the essential character of the system, and without any intervention of the rail on the flanges. There is no exception but for the first axle (leaving the engine aside, which forms a system apart); it is from the rails that axle receives the guiding action. It is the same with the last axle which becoming the first in the case of the train shunting, has also a guiding apparatus. This apparatus is formed of a frame $p\ q\ r\ s$ (Pl. XIII, *fig.* 17) encasing the axle and carrying four rollers which are applied on the edges of the heads of the rails. In spite of their inclination at an angle of about 45°, these rollers cannot pass the gaps in the crossings and sidings of ordinary roads; the appliances of these, permanent way of the *Sceaux* line, were consequently obliged to be altogether specially arranged. Of all the objections made against the articulated system, none of them have been so often brought forward as this one; it does away in fact, with any judgment of the system in itself; sufficient to condemning in general, is the fact that its stock can not run over other lines.

Although this objection is not the most grave, by a great deal, M. *Arnoux*, made a great many efforts to get rid of it; and he has succeeded therein up to a certain point, by adopting for the direction of the first axle, the arrangement which he had primitively adopted for the direction of the intermediate axles. But it seems to be the more useless to insist on this, as the solution of the normal direction of the first is and has been completely effected. To say truly I have never understood why M. *Arnoux* thus gratuitously outlaws his system, so to speak, when it was so simple to take instead of the axle with its concern of guiding rollers, either an American bogie, with axles very close together, of course with the wheels free, and no play in the road, or a *Bissel's* truck (185).

As to the connection which ensures the normal position of the axles, the direction of the first once assured, is is sufficient to point it out in the hypothesis which by the way has nothing objectionable in practice, of the equidistance of the axles. The perches $o\ k$, which fasten these carriages together have then the same length as the bar $M\ O$, which attaches the two axles in each of them. It is clear, that settled, that the necessary and sufficient condition of the position of the axles always normal to the line, is that each of them divides equally the angle formed by the perch and the bar ending at the turning pin, seeing that this perch and this bar are two equal chords of the arc of the circle along which the axis of the line is curved.

The condition enunciated was first fulfilled by the arrangement to which we made allusion just now. But it was complicated; it had, moreover the disadvantage of altering the symmetry of the vehicles, and consequently to require for shunting, the modification necessary in order to place in the convenient direction, the appliances for the convergence of the axles. The connection adopted afterwards, and due to M. *Arnoux's* son, an engineer of the « Corps des Mines, » is a great deal simpler; and it allows the symmetry to be retained; a glance over *fig.* 17 is sufficient to understand the principle; the four rods b, b, b, b, are jointed, on the one part, directly with the perch and bar, on the other with sockets m, m, run on the axle. These jointed rods being equal, the two triangles $a\ o\ m$, $m\ o\ a'$, are always equal, and consequently the axle om always divides equally the angle $a\ o\ a'$.

The slightly premature angular displacement of the axles, is evident. When a vehicle enters on a curve, its bar changes direction; it inclines to the following perch. The axle forced always to divide in two equal parts the angle of these two straight lines, turns then at that very moment round its pin, that is to say too soon, because it is still on a straight line. The same fact is reproduced in passing from a curve on to a straight line, but in that case

it is only a question of a slight theoretical imperfection, without any importance. If the objections against the articulated system were only of this nature, it would have easily got the better of them.

In the primitive stock the load was applied to the axles between the wheels as in carriages running on roads. Later, the inventor increased the breadth of the elastic base by taking the points of support outside the wheels, as on railways. The prolongation of the axle carries, in that case a plate s (Pl. XIII, *figs.* 14 to 16), curved on plan to the arc of a circle having its centre at the middle of the axle, and receiving a sliding piece equally curved g, fixed like the spring R solidly therewith, and being of sufficient length for the travel of the support s, carried with the axle in its movements of convergence.

The mode of lubricating and of isolating the oil merits attention. The reservoir ρ (*fig.* 14) is formed by a cylindrical cavity made in the journal and in its prolongation; it is closed in front by a screw plug b, and is fed by the oilcup γ. The nave of the wheel is tightened with very slight friction, between the shoulder e, of the axle, and the ring β screwed on to the screwed part of the axle.

Three small apertures o, o, o, establish the communication between the reservoir ρ, and the inside of the box of the wheel. The oil penetrates by this way, into the small interval comprised between the summits of the journal and of the box, and the rotation spreads it all round.

M. *Arnoux* thought of some very ingenious arrangements for allowing the articulated stock to enter into ordinary trains, to free the station people from the difficulties and the precautions to which they are subjected in moving about by hand, these special vehicles; but if these expedients are a proof of the inventive genius of their author they have no longer, at this date, any interest as regards applications.

185. There has been attributed, as regards curves, a special property to six-wheeled carriages, by which the intermediate axle would be the pivot, the regulator of the relative displacement of the end-axles.

In a very old arrangement (Pl. XIII, *fig.* 18), the end-axles having a convergent play, and the middle one having a longitudinal play, are connected two and two, by bars fixed onto them at right angles, and connected by articulations at the middle of the intervals between the axles. On a straight line, this connection keeps the end-axles from going away, to any extent, from their normal position, for they can only do so by displacing longitudinally the middle axle, and the action of the rails on the flanges of

its wheels opposes this. On a curve, if the vehicle be supposed placed bodily therein, the longitudinal movement of the middle axle, which brings back the bar, imparts to the end-axles the two movements centripetal and angular, necessary for their radial position, the middles o, o', o'', of the three axles placing themselves along the mean curve to which the rods $a\ o$, $a\ o'$, $a'\ o''$, are equal tangents. In reality it is the front axle which imparts the movement of displacement when the vehicle enters on a curve ; but the connection fulfills well the desired condition, and the middle axle without playing the principal necessary part, which is attributed to it, offers after a manner, by its transversal fixity a point of support to regulate the movements of the end-axles. But unless this third axle is warranted by the total load to be carried, its addition is not sufficiently justified by this result which can be obtained without it, and much more simply, by returning to vehicles with two axles, and applying to them the modifications indicated in the § 1st of this chapter.

186. *Carriages of the temporary railway over Mount Cenis.* (Pl. XIII, *figs.* 8 to 13). — It is on this principle, applied in a more satisfactory form, and combined with the independence of the wheels, that is founded the arrangement adopted, at the instance of Mr *Bruntees*, for the six-wheeled carriages for the *Mount Cenis* temporary line. In spite of the small gauge of the line: 3 ft, 16, the great distance apart of the axles : nearly 13 feet, and the extreme sharpness of the curves : 130 feet radius, of course urgently require great movability of the end-axles. Thus the application of the principle required details in accordance with the extreme conditions of the line.

Within certain limits, the bearing spring can remain solidly fixed with the axle, which it takes with it in its relative movements. It is sufficient to give the hangers a great length, and a very slight or even no inclination. Vertical when the carriage is on a straight line, the hangers, if they are long enough, are able to yield by a moderate inclination to the double movement of the axle; and this inclination and the non-symmetry which results therefrom, constitute for the axle, independently of all other connection, a tendence to retake the normal position as soon as it enters on to a straight line (183).

But this displacement of the spring, relatively to the frame, would attain excessive proportions in the carriages of the *Mount Cenis* railway. The springs do not therefore participate in the relative movements of the axles, on which they rest by the intermedium of a small block forming a slide g, and of a plate π, nearly the same as in the articulated system modified (184).

The end-axles can not then, be moved by the springs; that can no more be done by the guard-plates *p*, *p*, because of their very considerable play. It must then be done by jointed pieces, tying the axles together and ensuring their position, always normal to the line, whether straight or curve.

This system of pieces is double, and is placed symmetrically on each side of the vehicle. On the ends of the fixed axles are keyed rings *c*, *c*, *c*, jointed with rods *b*, *b;* but this connection, direct for the end-axles, is effected for the middle axle, by means of the cranked lever *h i k* and of the rod *l*, (*fig.* 11). It is evident that by this connection, every angular displacement of one of the end-axles, relatively to that of the middle, involves necessarily a displacement equal and contrary to that of the other end-axle, as well as a longitudinal movement of the middle axle, and reciprocally.

The cranked levers *h i k* act at the same time, with respect to that axle, as a complement of the guard-plates, which are much widened out, and on which their axis of rotation *i* rests. The arm *i k* is terminated by a sector *s*, *s*, (*fig.*11) described from the centre *i;* the axle-box is always enclosed without any play between the two sectors symmetrically applied on it, on one side and the other, and between which it slides under the action of the rods *l*, *l*.

The track of the *Mount Cenis* railway seemed at first sight to adapt itself badly enough to the application of this system, like every other, by the way, founded on the convergence of two axles at a great distance apart. The curves and the counter-curves succeed each other, often in fact without any tangent between them. The six-wheeled carriages passed through them however without difficulty, thanks to the central rail which guided them, and the yielding of the parts. But it is probable that the maintenance of the connecting pieces would suffer from this drawback.

187. *Bissel's-Truck.* — Of all the arrangements introduced, with respect to curves, into carrying stock, the most simple and perhaps the best, is that which bears the name of *Bissel*, and which rightly or wrongly, is claimed by others. It is greatly used for engines even in the United States. We shall thus return to it in its place, and it will be sufficient, here, to say a few words on its application to carriages.

A single axle, movable round a turning-pin placed through its centre, cannot keep on the rails without being guided. It can be kept on by means of M. *Arnoux's* guiding rollers, but it can also be kept in a manner a

great deal simpler, by a suitable displacement of the turning pin, brought either in front of or behind the axle. On a straight line, the axle can only deviate from the position normal to the axis common to the line and the vehicle, on account of the play between the rails, and at an angle which is the smaller, the greater the distance from the axle to the turning-pin. But this distance is determined. The two end-axles and the transverse axis of the vehicle (whether there is or is not an axle in the middle), having to converge towards the centre of the curve, it is evidently at the middle of the distance between the two adjacent axles, the one fixed and the other movable, that the turning-pin ought to be placed.

The middle axle is besides useful, if not necessary so as to keep the transverse position of the frames fixed relatively to the line.

If instead of a single axle, we consider a group of two or more parallel axles having to take an angular movement, relatively to the other groups, the excentricity of the turning-pin has a considerable advantage, especially for engines. It is one of the essential characters, the sole indeed, of *Engerth's* engine.

The transverse displacement of the axle must besides always, as much for obviating the oscillations of the axle on a straight line, as for assuring its immediate return to the normal position when it leaves the curve, give rise to reactions tending to bring it back to this position, which it ought only to quit for the necessary space of time.

In engines, the frame rests on the bogey, not directly by the bearing-springs, which are fixed, and do not participate in the angular movements of the front bogey, but by the intermedium of sliding blocks with inclined planes, whence results the tendency in question. In waggons it results simply from the inclination which the hangers of the bearing-springs take, solidly fixed with the axle and taken by it (183). In the normal position, corresponding to a straight line, these hangers are vertical. In order that they should all take the same inclination on curves, their length ought evidently to be proportional to their distance from the turning-pin.

The steel-carriage of the *Oudh and Rohilkund* railways and that of the *New South Wales* line constructed by Mr *Fowler*, offer two examples of this mode of connection, applied to six and eight wheeled carriages. A triangular frame fixed to the axle-boxes, connects each one of the end axles to a turning pin I (Pl. II, *figs.* 9 to 11).

The springs of these axles ought to be stronger than those of the intermediate axle or axles, to allow for the effort which is brought on them

on curves, by the horizontal transversal components of the torsion of the hangers.

188. *Couplings.* — The arrangements which we have just rapidly reviewed, suppose necessarily between the radii of curvature, and the length of the frames, such a relation, as that the mode of coupling leaves the flexibility of the system of the vehicles intact. Coupling with two buffers in contact ought thus to disappear or at least be modified, as in the *Metropolitan* carriages (135); but if this arrangement eliminates the drawbacks attending the contact of buffers on a curve, it reduces remarkably, also, their advantages on a straight line. Far better in such a case, to do away with the contact of the buffers, unless indeed with double buffers as Mr *J. Edwards Wilson* has done for the Oudh and Rohilkund railway-stock (Pl. II, *figs.* 9 to 12) and M. *Pihl* for the Norwegian narrow-gauge stock (Pl. VII, *fig.* 11).

But coupling properly so called, that is to say, the mode of transmission of the effort of traction, is often modified also. The disadvantages involved on a curve by coupling on with hooks solidly fixed transversally to the end cross-beams of the frames, have been much discussed. It will be remarked that the normal position of a vehicle on a curve, is that for which its transverse axis coincides with the radius, and that the couplings ought to tend as much as possible, not to deviate it therefrom, but to bring it back if required.

Without doubt; but the individual tendency of each vehicle is to place itself obliquely to the line, acting against the outside rail by its front wheel (178) and it is evident that the connection effected by a coupling bar *a b*, between the middles of two cross-beams, tends to correct this obliquity, seeing that the effect of its tension is to make each of the vehicles pivot in the suitable direction, round the vertical passing through its centre of gravity (Pl. III, *fig.* 14). It is true that if the obliquity of the coupling-bar tends to diminish the obliquity of the carriages on the line when it works by traction, it tends on the contrary to aggravate it, when it is in compression, which takes place when the head of the train slackens speed, or when it is shunted. It is from this point of view only that the complaint made of this coupling is well founded, and whence it can only be made as regards rigid bars, such as those of American-stock, and not to ordinary articulated systems such as the screw couplings, or simple chains, in the case of which the effort of shunting is transmitted by the buffers. This mode of coupling only becomes in general, really defective, if the length of the frames goes

beyond a certain limit, not absolute but relative, to the radius of the curve. Then, in effect, the effort of traction is transmitted in a direction too oblique to the line. To diminish this obliquity without increasing the distance apart of the carriages, we can place the attachment, not on the end cross-beam, but at a point of the longitudinal axis of the frame more or less close to the centre of its figure, or what amounts to the same if the vehicle has one continuous draw-bar, to place a joint on that bar.

The stock already so often cited of the *Oudh and Rohilkund* railways offers an example of this arrangement. The joints O, O, (Pl. II, *figs.* 9 to 11) are placed at 17 ft, 22 from the end cross-beam. The traction is thus effected in the same condition as if there were carriages to deal with of 22 ft, 97 long, instead of 60 feet coupled at intervals of 35 ft, 43 ($2 \times AO$).

If with carriages of a length so considerable, this arrangement presents some advantages, it is clear that at a high speed, it would not be favourable to stability. A carriage thus coupled is evidently more disposed to oscillate horizontally, than when it is maintained by end-couplings.

189. To terminate this examination of carrying-stock, there remains the brakes for us to study. But the engine and its ordinary adjunct, the tender, are vehicles, and they can in this respect also receive regular brakes; the tender indeed is always provided therewith. The engine itself, which produces, can also check the speed, and bring when required, a considerable contingent to the means of stopping with which a train ought always to be provided. It is convenient to adjourn the study of waggon-brakes, so as not to break up the investigation of the means of stopping. It is natural besides, only to treat of the reduction of speed, after having studied the production thereof.

BOOK THIRD.

TRACTION.

CHAPTER I.

PRELIMINARIES.

190. The simplicity of the locomotive, the great power it possesses in a small compass, and with small weight, the facility with which it adapts itself to the most varied conditions of work, render it a veritable mechanical master-piece,

Looking at the complicated nature of the problem, and the simplicity of the means employed, the solution is marvellous. But after having, at first, had too little faith in the resources of this precious instrument, it has now come to be considered as sufficient for everything; that the locomotive is for ever and aye, the mode of traction *par excellence;* that railways ought to be laid out in accordance with its requirements, and that while we do our best to modify them, it is useless to seek elsewhere, as regards the principle.

It can not be denied, that with regard to curves, the locomotive has succeeded in obtaining a sufficient relative flexibility up to a limit of radius at first despaired of; but this property is only gained at the expense of the effort of traction which the machine can develop at a low speed, of its safety in running at high speeds, and of the simplicity of its construction.

It is above all, for inclines, that the progress has surpassed every expectation. At first railways scarcely emerged from the horizontal; then they reached successively to gradients of one in 100 — one in 50 — one in 33 — one in 27. The locomotive is still equal to the task; and so, without any question as to cost, on people go, at least with projects; and gradients are dreamed of, even for great lines, of one in 25 — one in 22 1/2 — one in 20, etc.

But experience soon brings back a sounder appreciation of matters; it must be frankly admitted that, beyond a certain limit of gradient, a limit from which it is more and more difficult to escape as the systems of lines extend, the locomotive whatever may be done, yields only a trifling useful effect.

Like every instrument of work, in effect, it has its sphere of application, of great extent, doubtless, but beyond which it is as lost, paralysed even. At first rare, the circumstances in which it can be maintained only by straining its natural condition become more frequent. The moment thus arrives, for seriously thinking of taking advantage of fixed motors, too readily resorted to at the outset of railways, but too much neglected now-a-days, in spite of the progress made in the transmission of power to a distance.

If the difficulties of a line were concentrated, instead of being divided as has been done, over a large extent of line; if they were laid out in divisions easily accessible to locomotives, joined by very stiff gradients worked by fixed motors, the maximum of economy, both of construction and working would often be reconciled. This division already applied to purely industrial lines, can also be so to crossing mountain-chains by great lines. While accepting tunnels of great length (indispensable besides, whatever may be the mode of traction, in avoiding the difficulties of every kind which carrying on a great traffic would encounter at very great altitudes) locomotive lines cannot generally, reach these summit tunnels excepting along a very sinuous and very steep course, inflicting heavy charges on construction as well as working, which a radical change of system would at times allow a very great reduction in.

191. With these exceptions, still rare, but become, at this time, so important, the locomotive will remain, without doubt, master of the situation. It is the locomotive that should be studied before passing on to the solutions applicable to extreme cases, but confining ourselves at first to the dispositions which are in immediate relation with the nature and particular conditions of the transmission of its work.

As a steam engine, the locomotive differs in no essential character from fixed engines with direct transmission, and without condensation. If the arrangement of the evaporating apparatus was long peculiar to locomotives, it is no longer the same now, that arrangement being widely spread among industrial works, on account of the advantage possessed thereby of concentrating great power in small compass, with little weight.

What characterises the locomotive, is not, then, the mode of producing mechanical work, but its mode of transmitting the same.

In locomotives, as in fixed engines, the work is delivered by the pistons to a driving shaft; but this shaft is also a bearing one, and necessarily much loaded. The moving apparatus, on the one hand, the vehicle on the other, form two quite distinct groups. It is the arrangement of the vehicle which gives the different types their peculiar character. Engines intended for high speed, or low speed; for lines with large curves, or very tortuous; for lines with steep gradients, or on the contrary for lines nearly horizontal, can be appropriated to these divers conditions, with the same moving apparatus working with the same velocity of piston. They only differ by the vehicle.

192. The locomotive will be then first for us a vehicle having the generating and moving apparatuses for load, and of which one of the axles receives from that motor, a movement of rotation. This study in part, comes naturally after that of carrying-stock, with which the vehicle of the engine has necessarily many points in common. It is above all from its disposition, and the cramped way in which the work of the driving-shaft is transmitted, that are derived the conditions imposed on railways as regards their plan and section; conditions which it is impossible to avoid, and often very difficult to satisfy fully. We shall be able, by thus separating the study of the locomotive, to discuss the most important questions of traction, first clearing away all details connected with the motor proper. These special details have only a secondary interest for engineers occupied in laying out lines: a very complicated subject when all the elements are taken into account. If they have to study also the question inseparable from their work, that of the type of engine to adopt, these same engineers are rather indifferent to purely mechanical details, and they can, once the general plan of operations is decided, refer this point to locomotive engineers. The order we adopt has then, in this respect, positive advantages. The locomotive once studied as a tractive apparatus, as motor-vehicle, it will remain for us to study the production of work by the boiler, and the transmission thereof to the driving axle.

The same motive will lead us to follow the investigation of the locomotive as vehicle, by that of the processes of traction by fixed engines. We shall thus group together the facts and considerations connected with the capital question of laying out lines, and the modes of traction thereon, regarded in all its bearings.

We shall have besides no scruple, in considering as known, those elementary principles, known, in fact, to every one. We shall be enabled thus to be briefer, than by restricting ourselves to a strictly didactic order of proceeding.

CHAPTER II.

ADHESION.

§ I. — Its character.

193. It is necessary first of all, to analyse and follow through its consequences, the fact which is the characteristic of the locomotive, that is to say the transmission of the effort of traction by means of the tangential reaction of the driving-wheels and the rails, that is to say, the *adhesion.*

If the rails and the driving-wheels were provided with teeth, the movement of rotation would necessarily involve, for the engine and for the train attached thereto, a movement of translation, having for velocity, that of the wheels at the circumference, and the sum of the pressures between the teeth in gear would be equal to the resistance to traction of the whole train, engine included. This gearing exists, only the teeth are microscopic, and it has for limit the friction, a variable, capricious element: that is the fault of this intermedium; but it amply compensates therefore, by its simplicity.

As long as the effort of traction necessary for the progress of the train is inferior to this limit, the friction, the movement of translation takes place; but if it attains that limit the wheels slip round in their places and the work of the motor is taken up in pure loss by the resisting-work of this slipping. Moreover, the acceleration of the movement of rotation which is the immediate consequence of the slipping, may put out of order and break the parts of the machinery, if the driver does not hasten to shut off the steam.

We are so habituated to see the locomotive take hold of the rail by the imperceptible asperities of its polished tyres, that it seems to us that an idea so simple in appearance ought to have been applied from the very first. It was so, in fact, at the outset, but in order to be soon given up again. A locomotive constructed in 1804, by *Trevithick*, for the *Merthyr Tydfil* railway, and with smooth tyres, worked at first by adhesion, which seemed sufficient even at a small velocity, 5 miles an hour; but soon its variations and its insufficience became manifest, which was in no way to be wondered at, with such a low speed, in spite of the certainly considerable weight of

the engine relatively to the effort of traction which it was capable of developing even at that low velocity. *Trevithick* sought then to make up for the adherence, and from that time out, that is to say, in the very infancy of railways, engineers puzzled their heads to find out expedients for offering the effort of traction a less unstable point of support than adherence. In 1811 Mr. *Blenkinsop* carried gear work into effect for the purpose by a rack applied alongside one of the rails. The connecting-rods worked on to a shaft which conveyed the rotation by means of gearing to the driving, but not bearing shaft, on one end of which was keyed a large toothed wheel, taking into the rack. This expedient of the rack, which we shall find reappearing much later, but under quite special conditions, worked for some time on the railway from *Middleton* to *Leeds*, in the carriage of coal. It was applied also, towards the same period, under other forms. Thus in 1812, Messrs. *W.* and *Ed. Chapman* tried a chain fixed at the two ends and laid along the centre of the line, and into the links of which a central toothed wheel geared.

194. *Condition of the adhesion.* — An error was thus fallen into going away from the true solution, foreseen however, when at last in 1813, Mr. *Blackett*, the first to believe firmly in adherence, maintained that it was sufficient in most cases, and proved.

The tangential reactions of the rails on the driving-wheels being equal to the effort of traction, the latter has, as well as the first, for limit the friction. The effort of traction which an engine can exert has thus a maximum, independent of its dynamical power, and proportional to the load on the rails of the driving wheels, that is to say to the adherent weight.

p being the effective pressure of the steam in the boiler, 0,65 p (according to the generally admitted coefficient of reduction) the mean effective pressure on the pistons, the sum of the pressures exerted on them is

$$\frac{1}{2}\pi d^2 \times 0,65 p.$$

The coefficient of reduction 0,65 takes into account in one figure, of the fall of pressure from the boiler to the cylinders during the admission, and of the use of the expansion within ordinary limits.

l being the stroke of the pistons, D the diameter of the driving wheels, the mean velocity of the pistons, and the constant velocity at the circumference of the wheels, that is to say the velocity of the train, are to each

other in the ratio of the distances gone through in one turn of the wheel: $2l$, and πD.

The effort of traction is then:

$$\frac{1}{2}\frac{\pi d^2 \times 0,65p \times 2l}{\pi D} = \frac{0,65pd^2}{D},$$

a value which exceeds the effort which an engine can really apply to the haulage of a train, its own weight included, by the force which measures the interior resistance of the engine, that is to say, the resistance of the mechanism, from the pistons up to the driving axle.

P being the weight of the engine, $\frac{P}{n}$ the amount of adherence, f the coefficient of friction, we have thus the condition as it is ordinarily given,

$$\frac{0,65pd^2l}{D} \leqq \frac{fP}{n};$$

The first member should in reality be diminished by the resistance of the moving parts; but in neglecting this correction, we only aggravate a little the condition relative to the adhesion, which presents no disadvantage.

195. *Relations between the velocity, the diameter of the driving wheels, and the adherence.* — We can in general, judge at the first glance, if a locomotive is intended to work at a high, a low, or a mean velocity, and the characters of difference are entirely in the vehicle.

Let there be two engines identical as regards boiler, as regards machinery, and one having to draw an express, the other a goods-train; $T^{\text{ft pds}}$ being the available work in the unit of time on the driving axle, V^{ft} the velocity, N the number of revolutions per second of the driving axle, t^{lbs} the effort of traction, or its equal the tangential reaction of the rails on the driving wheels, r their radius, we have:

$$V = 2\pi r N$$

$$T = tV$$

$$t = \frac{fP}{n} \text{ (at the limit)}.$$

At equal values of T and N, r is then proportional to V, and $\frac{1}{n}$ proportional to t, and consequently inversely as V.

If, for example, the passenger engine ought to go at double the velocity

of the goods-engine, it ought to have driving-wheels of double the diameter, while the second requires an adhering weight twice that of the first.

The exact proportion of the diameter of the driving-wheels to the normal velocities, the equality of the velocities of rotation of the driving axles, for engines identical as regards mechanism, is doubtless not necessary, but there two characteristics none the less exist: large driving wheels and partial adherent weight for passenger engines; small wheels and large, sometimes total adherent weight for goods engines, or low speed. Between these two extremes come the engines of mean velocity, characterised, the generating apparatus and motor being always supposed identical, by an intermediate diameter of driving wheel, and adherent weight.

The differences in the diameters of the driving-wheels and the adherent weights, all things equal besides, have then the effect of causing the two factors to vary in a determined ratio : effort of traction, velocity, of the available work on the driving shaft.

196. It is evident that this *exchange* between the velocity and the effort, is constantly at work in the same engine. Having to draw its load over gradients more or less variable, it can only do so, with equal work, in proportioning at each instant, its velocity to the effort of traction which it ought to exert; but this exchange is only possible between certain limits. One of the factors, $\frac{d^2 l}{D}$ being constant, the other, that is to say the mean effective pressure $0{,}65\,p$ in the cylinders, must vary inversely as the velocity.

As one may conceive, this proportionality can be established, the effective pressure in the boiler being always kept at its maximum p, and the production as well as the expenditure of steam being constant.

If for example, the velocity diminishes, the mean pressure on the pistons is increased, by a longer admission. This pressure during admission, increases besides, on account : 1. of the less velocity of the piston; 2. by the less wiredrawing of the steam, in its passage through the ports, more fully uncovered by the slides; 3. by the less back pressure on the pistons, which on the return stroke, find in spite of more considerable quantity of steam admitted during the preceding stroke, the back pressure more reduced, the exhaust having been in action longer, at the moment the piston acquires a notable velocity.

There is never occasion to admit the steam during the whole stroke. The arrangement of the machinery would not besides allow of it. The ad-

mission can not be *nil*, with the regulator open, the slide still admitting a little at the notch corresponding to the dead point, nor prolonged during the whole stroke; and indeed it scarcely ever occurs that the admission is pushed to the limit, variable besides, which results from this arrangement. The steam would then be badly utilised; the consequence of the intimate dependence which exists, in the distribution by slides, between the circumstances of admission, and those of exhaust.

197. *Relation between the adherence and the volume of the cylinders.* — The volume of the cylinders is mostly determined in practice, by the condition, that the effort of traction should exceed the adherence, in the mean state of the rails and with the normal pressure in the boiler, and that consequently the wheels slip on the rails for an admission which varies from 40 to 60 per cent of the stroke, and often nearer the first figure than the second; in such a manner that a more prolonged admission could only be, at the most, warranted by a value of the adhesion superior to its ordinary value, or by a reduction in the pressure in the boiler, a fact which should in general be avoided.

In a note published (*) in 1863, M. *Biglia* inspector of the " Ponts et Chaussées, " in Italy, expressed himself on the subject of the adhesion of the engines which work the " Giovi " incline (line from *Turin* to *Genoa*):

" In ten years and more of working, it has never once happened to us to be able to work with the whole moving power of our engines, *that is to say without expansion*."

In announcing this result of experience as a proof of the exaggeration of the value attributed to the adherence on the *Giovi* incline, in a note which he attacked rightly besides, M. *Biglia* expressed simply a general fact, and one *purposed* : locomotives are never made to work with the full admission of the steam. What " did not occur once in ten years " at Giovi, occurs nowhere else either, unless the suitable relation between the dimensions of the cylinders and the usual value of the adhesion has not been kept to.

198. *Of the adhesion during the period of acceleration at starting.* — The condition : effort of traction $\leqq \frac{fP}{n}$ ought to be satisfied for the max-

(*) *Réfutation d'une note de M. Gouin, constructeur de machines*, p. 10; Turin 1863.

imum effort of traction, and consequently for the minimum *uniform* velocity, at which the engine has to run, upon the more or less steep gradients which it meets with.

Before attaining a given velocity, the engine has to pass through all the intermediate degrees; but it is not evidently of the very small velocity, *nil* even at starting, that the question is, in determining the condition of adhesion. This will be at once understood, if it be observed that the load of the engine is fixed according to the maximum velocity at which it has to run on a given line, on a horizontal or on an incline. It is with this load only, and not with that which would correspond on the same line to a velocity almost *nil*, that it has to start; and as the resistances, and consequently the effort of traction, with an equal load, are as much less as the velocity is less, it results therefrom, that if the two conditions, the one of the dynamical power, the other of adhesion, are satisfied for a certain velocity, they are also satisfied, *a fortiori*, for the velocities through which the engine has to pass, before attaining the same.

It must not be concluded therefrom, however, that no notice must be taken of the adhesion, during the period of acceleration which precedes the getting into the usual speed. It is, on the contrary, then, that the tendency to slipping is greatest. Not that there is any special resistance at starting, unless perhaps in some circumstances altogether peculiar (210); but it is that the effort of traction has to exceed, at each moment, the resistance of the force necessary to impress the mass of the train a velocity pretty rapidly increasing.

If this excess were too slight, the starting would be slow, and there would result, for trains with numerous stoppages, a great loss of time. This disadvantage would besides, affect light and rapid trains, as well as eavy and slow trains; th e first, for which time is also more precious, would be, in spite of their less mass, too long in getting up their regular velocity, of course much greater.

If the condition relative to starting, may in general be looked upon as comprised in that which is derived from the consideration of the utilisation of the work, supposed constant, at the lowest uniform velocity, this last condition must have been taken very full.

Difficulties in the starting would otherwise be likely to arise, whenever the state of the rails was not very favourable.

199. *Inferior limit of the velocity of engines, independently of the adhesion. — Necessity of then renouncing direct transmission.* — If an engine can-

not utilise its power at a velocity much inferior to that for which it has been built, because the adhesion would fail, there is also an absolute minimum below which this normal velocity cannot go, without recourse being had to special arrangements.

$T^{h.p.}$ being the available work, per unit of time, at the driving axle, $V^{b''}$ the velocity, ρ^{pds} the resistance of the working parts, we have (194):

$$\frac{T}{V} + \rho = \frac{0,65 pd^2 l}{D},$$

or U being the volume of one cylinder, that is to say $0,785\, d^2 l$,

$$\frac{T}{V} + \rho = 0,82\, \frac{U}{D};$$

if we neglect ρ against $\frac{T}{V}$, the function $\frac{U}{D}$ is inversely proportional to V.

It is necessary then, for a very small value of V, to employ either very large cylinders, or very small wheels, or both. But difficulties and even impossibilities of construction soon came forward with too small wheels (disadvantageous by their very smallness besides, as regards the tractive force) the machinery comes down too low: the big end of the connecting rods would reach down to the ground line, and even below it. If increasing the volume of the cylinders be desired, they must have an excessive diameter, and consequently improper proportions, or a long stroke, which would have the same drawback as wheels too small. Dimensions are obliged to be kept to, for both of them, which differ little from those which correspond for equal power of engine, to ordinary low speeds, and which are incompatible with the condition $\frac{T}{V} = 0,82\, \frac{U}{D}$. Hence the necessity of giving up the equality of the number of double strokes of the piston and of the number of revolutions of the wheels, that is to say, direct transmission. The pistons reduced to ordinary diameters and strokes, but going at a speed which would correspond, with direct transmission, to a velocity of translation very much higher, and to an effort of traction very much lower than those required to be obtained, can thus make use of all the steam produced by the boiler; and the transmission by gearing of the driving-shaft with the axle of the driving-wheels, reduces in the required ratio, the velocity of rotation of the latter, by increasing correlatively, the effort of traction.

In discussing, in 1869, the conditions of the working of secondary lines of railways, the technical commission of the " Union of German railways," took specially into consideration, industrial and mineral lines, upon which

the velocity can be greatly reduced, with much advantage to economy; it adopted the establishment of a special category of trains characterised by a maximum speed of 40 minutes for 1 German mile, or 6,32 miles an hour, and a prize was offered by the direction of the Rhenish railways, for a type of engine appropriated to these conditions. At such a low speed, the difficulty appears to be more to obtain the necessary amount of adhesion, than to deal with the machinery, and that particularly on colliery lines, the rails of which are almost always covered with coal dust.

§ II. — **Measure of the adherence.**

200. *Mr. Wood's experiments.* — The coefficient of friction plays then a most important part in the effective work of locomotives. It is of consequence to know its value, that which can be adopted in each case with security, without the risk of exposing the engine to fail in power, of putting it into a state, in which it can not develop, at the required speed, the mechanical work, it is capable of furnishing.

Although adhesion showed long ago what it could do, its usual value, and its minimum value, were for a long time taken too low in Europe. This was the remains of the old opinion of its radical insufficiency (193). What is really its minimum was taken for its ordinary value, a minimum rarely reached, and which does not go below $\frac{1}{16}$. The first experiments made with some precision, appear to be those of *Nicholas Wood.* He proceeded by the estimation of the effort of traction which gave the adhesion *utilised*, that is to say a minimum of the available adhesion or its very value when the tendency to slip, showed the limit was reached.

Mr. *Wood* found (*):

On rails perfectly dry.......................... $\frac{1}{7}$

On rails damp or dirty......................... $\frac{1}{12}$

On rails very greasy........................... $\frac{1}{25}$

(*) *Treatise on Railroads,* p. p. 93 and 95.

He also showed that the adhesion is the same (*) " on rails perfectly dry, or on rails perfectly wet."

M. Seguin sen. is equally precise on this last point :

" The adhesion of the rails, " he says (**) " produces its most complete effect when the rails are perfectly dry, or inundated with water. On the *St. Etienne* line care has been taken to provide on the engines four small jets which are supplied from the tender, and keep the rails continually watered. This means has succeeded the best among all the trials I have made."

The observations of Mr. *Wood* were made on an engine with cast-iron wheels, and without springs. " Later, when springs were adopted," says Mr. *Wood* (***) " the value of the adherence was more considerable." He admits that on the greasiest rails it did not go down below $\frac{1}{20}$.

The presence of springs, the influence of which Mr. *Wood* does not explain, is certainly, not by a long way the principal cause of the higher value of the coefficient, obtained with engines on springs. These engines differ from the first, not only by the springs, but also by the position of the cylinders, vertical in the ones, horizontal in the others. The first position much aggravates, and brings to a maximum the influence of the parts with relative movements, on the load of the driving-wheels, a load which is then, at each half revolution, alternatively greater and smaller, than the statical load; now it is evident that from the point of view of adhesion, there is in no way, compensation between the increments and the diminutions; the latter determine a succession of slippings, and the position approximates more to that which would correspond to a constant load equal to the lower limit, than to that which would correspond to the higher limit.

Mr. *Wood*, besides, experimented on the roads of colliery lines, in stations badly kept, and consequently on rails the state of which was far from representing the mean state of the actual permanent way on the great line.

201. *Values admitted in the United States.* — In the United States, at the outset, as much was demanded from adhesion as it could give.

(*) *Treatise on Railroads*, p. 93.

(**) *Des chemins de fer*, p. 439.

(***) *Treatise on Railroads*, p. 94.

In 1838 Mr *H. Latrobe* (*) indicated the coefficient $\frac{1}{7,5}$ as admissible with perfect safety. A little while after, in 1839, Mr. *W. Casey* pointed out, in the *American Railroad Journal*, the far too low estimate, according to him, admitted even in the United States; and he established the fact that as far back as 1836, engines of *Baldwin* and *Norris* were working, developing a tractive power which reached the third and even the half of the load on the driving-wheels. But those were certainly very high limits, ascertained under exceptional circumstances, and on that very account offering little interest. It is clear, besides, that if in the same place the coefficient varies from one moment to another according to atmosphere conditions, its mean usual value varies also from one place to another as the mean itself of these conditions. Thus the climate of North America is generally more favourable to adhesion, than that of Europe. Thus also, and without going so far, while on the Semmering the adhesion utilised, generally reaches $\frac{1}{6}$, between *Pontedecimo* and *Busalla* (*Genoa* and *Turin* line) it never exceeds $\frac{1}{8.4}$ in the open; in tunnels where it is really constant, it hardly reaches $\frac{1}{10}$, and that be it understood, only with the use of sand (**).

It will not do then to generalise.

The influence of certain states in the surfaces of the rails is proved by daily experience. Damp, hoar-frost, dew, fog, coal-dust, dead leaves, etc., lower the coefficients, and cause the wheels to slip. It is the same with rain, at the beginning or at the end. But as long as the rails remain thoroughly wet, they are nearly in the same conditions of adhesion, as dry rails.

Other causes, fortunately quite accidental, may lower the adhesion. The 2nd July 1871, a train came to grief near *Méximieux* (*Lyons* to *Geneva* line), a swarm of locusts having been crushed on the rails, and caused such an amount of slipping, that two coupling rods broke.

202. *M. Bochet's experiments.* — If the action, incontestable besides, of water in the vesicular state, as that deposited by fog, seems quite natural, it is less easy to conceive that water in the liquid state, injurious in a small

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(*) *Report on the organisation of the service of the line from Baltimore to Ohio.*

(**) *Biglia. Réfutation*, etc., p. 6 and following.

quantity, ceases to be so when the quantity increases. Experiments made by M. *Bochet, ingénieur en chef des Mines*, would seem to show that the anomaly does not exist. Measuring by the dynamometer " totaliseur " the resistance to traction of waggons sliding either with their wheels skidded, or on drags shod with iron, supporting the frame M. *Bochet* (*) found that :

The state of dryness, or of *greater or less dampness* of the rails has no sensible influence on the friction of the iron, any more of the wheels at the commencement of their slipping, as later, than of the skids with different extents of surface. " The friction " he says farther on (**) " did not change, whether the rails were dry, damp, or quite covered with water."

If this result seems in contradiction with experience, it is, according to M. *Bochet*, because experience shows, when the rails are wet, not the inferiority of their friction, but the less force of the brakes (***). Now the blocks being generally of wood, their own dampness, or that which is brought on them from the rails by the tires, lowers their coefficient, and thus requires them to be tightened more to skid the wheels, or rather to bring them to a point short of skidding, which is a more favourable condition for checking the momentum of the train. But if this explanation is admissible to a certain degree, it is applicable neither to brakes with cast-iron blocks, nor to a fact established also by practice, and more frequently still than the reduced action of wooden brake-blocks, that is to say the greater tendency of engines to slip when the rails become damp.

What constitutes the anomaly, is not that simple dampness diminishes the adhesion, but that complete wetness does not diminish it. If water in a small dose acts up to a certain point as a lubricating medium, it is difficult to conceive why this action, instead of increasing with the amount of water, should cease; that is explained however, in a certain degree, by remarking that if very little water only moistens the particles adhering to the rails, plenty of water washes them off; in any case, as the fact is established by daily practice, always more conclusive than experiments however well made, we have only to accept it.

203. *Experiments of MM. Vuillemin, Guébhard and Dieudonné.* — The uniformity resulting from the experiments of M. *Bochet* has not been con-

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(*) *Annales des Mines*, 5th series, vol. XIX, p. 61.
(**) *Do* p. 91.
(***) *Do* p. 62.

firmed by those of MM. *Vuillemin*, *Guébhard* and *Dieudonné* (*). But the mode of observation adopted by these engineers, who experimented as Mr. *Wood* did, on a running train, was less direct than that of M. *Bochet*. They obtained the amount of the adhesion utilised, by adding to the effort of traction on the coupling bar, given by the dynamometer, the calculated effort corresponding to the engine itself. The total effort divided by the amount of the adherent weight, gave a minimum of the coefficient, or its exact value, when the engine was at the slipping limit.

These are the figures obtained by the authors of the work in question (**):

dry weather . . . . $\left\{\begin{array}{l} \frac{1}{7,5}\ \frac{1}{7,6}\ \frac{1}{5}\ \frac{1}{6,6}\ \frac{1}{8,8}\ \frac{1}{6}\ \frac{1}{8}\ \frac{1}{6,8}\ \frac{1}{7,4}\ \frac{1}{7}\ \frac{1}{8,1}\ \frac{1}{8}\ \frac{1}{9,5}\ \frac{1}{8} \\ \frac{1}{5,9}\ \frac{1}{6,3}\ \frac{1}{5,3}\ \frac{1}{4,4}\ \frac{1}{5,6}\ \frac{1}{5,3}\ \frac{1}{5}\ \frac{1}{5,2}\ \frac{1}{6,1}\ \frac{1}{7,4}\ \frac{1}{6,2}\ \frac{1}{7,7} \\ \frac{1}{6,1}\ \frac{1}{5,7}\ \frac{1}{6,1}\ \frac{1}{6,4}\ \frac{1}{6,1}\ \frac{1}{6,3}\ \frac{1}{5,2}, \end{array}\right.$

weather a little damp . . . . $\frac{1}{7,6}\ \frac{1}{7,2},$

damp weather . . . . $\frac{1}{12,8}\ \frac{1}{6,1},$

slight rain . . . . $\frac{1}{11,1},$

rain . . . . $\frac{1}{8,4}\ \frac{1}{9,2}\ \frac{1}{8,8}\ \frac{1}{11}\ \frac{1}{8}\ \frac{1}{5}\ \frac{1}{4,9}\ \frac{1}{6,5},$

rain and fog . . . . $\frac{1}{8,7}\ \frac{1}{7,6}\ \frac{1}{6,9},$

heavy rain . . . . $\frac{1}{6,3}\ \frac{1}{6,3}.$

The coefficient lowers then when the weather passes from dry to damp, or to slight rain, and it rises if the rain becomes heavy. Heavy rain is no more unfavorable to adhesion than dryness, a result already arrived at by Messrs. *Wood* and *Seguin* (200). It is indeed to the heaviest rain that the highest value $\frac{1}{4,9}$ obtained in the preceding series, corresponds. But this occurred at starting the train, a circumstance which can very well account for the excessive value (210). It is the same as regards the figure $\frac{1}{6,1}$, which is very high for damp weather.

(*) *De la résistance des trains*, etc., p.p. 61 and following. *Lacroix*, Paris 1868.

(**) *Do* p. p. 61 and following.

The authors conclude, altogether, from their observations (*):

1. That the maximum during running, is $\frac{1}{5}$, and that this value ought to serve for fixing the maximum load that engines can draw in fine weather;

2. That for a minimum load to be drawn in all weathers, $\frac{1}{9}$ is the most suitable figure, and that a greater value could not be reckoned on in winter.

204. *Value of the adhesion deduced from the load drawn up a steep gradient.* — It is easy to find out by calculating the tractive effort that on rails in good order, this effort reaches and even goes beyond the one fourth of the adherent weight. Steep gradients are more favourable for this calculation than horizontals, gravity then constituting the principal element of the tractive effort, so that the uncertainty bears only on the resistance proper of the train, that is to say on a small item.

Let us take some examples: 1. On the incline of one in 45, on the North-London, an engine weighing full 45 tons, but with only 32 tons adherent, takes up, with the rails in good order, a load of 314 tons, or in all 359 tons. The resistance due to gravity is $359 \times \frac{1}{45} = 7$ tons, 898, or alone itself, very nearly one fourth of the adherent weight. It is true that this weight of 32 tons on the level, is a little greater on the incline, on account of the coupled wheels being behind; but the effect of this is very far from compensating for the resistance proper of the train.

2. Observations made on the *Don Pedro* railway of Brazil lead to the same result. This line passes over, between *Rio de Janeiro* and the *Parahyba* river, a chain of mountains crossed by a tunnel a mile and a half long, approached on both sides by a gradient of one in 55. All the works having been completed three years before the tunnel, a temporary line was laid over the mountain, with gradients of one in 19, curves of 400 feet radius, and one of even 250 feet. The line was worked by one of *Baldwin's* eight-wheeled engines, the whole of the weight of which 28 tons, 5, was adherent. They took up 80 tons: the effect of gravity was $(28,5 + 80) \times \frac{1}{19} = 5$ tons, 75, or $\frac{1}{5}$ of the adherent weight. Taking into account the resistance proper of the gross load, which is about 1100 lbs on a straight line, and very much in

(*) Page 64.

creased on such sharp curves, it must be admitted with certainty, that the effort of traction reached at least the one quarter of the weight of the engine. The working was never troubled by slipping, always however with the use of sand when required by the weather.

We shall revert to the remarks on this subject when treating of traction up inclines.

On a horizontal, the direct measure of the effort of traction requires the application of the indicator, the diagrams of which give the mean effective pressure on the pistons, the sole unknown quantity of the function (194), which represents the effort of traction, augmented by that which measures the resistance of the machinery.

On the *Brentwood* incline, one in 90 (Great Eastern) the service is done by engines weighing full 31 tons, 5, of which 21 ts, 25 are adherent. The indicator shows a mean effective pressure in the cylinders of 115 lbs on the square inch; the pistons being 1 ft, 41 in diameter, and having a stroke of 2 feet, the coupled wheels 6 feet in diameter, the theoretical effort of traction is $\frac{115 \times \overline{1,41}^2 \times 2}{6} = 10,973$ lbs. Deducting the resistance of the machinery or at the most 1, 100 lbs, gives for the real tractive effort, that which ought to be at most equal to the adhesion : 9,873 lbs, or $\frac{1}{4,7}$ of the adherent weight.

205. *Influence of the nature of the metal on the adherence.* — The rapid wear of iron tyres, especially for driving wheels, leads more and more to the substitution for them of cast steel tyres. Some engineers feared that this substitution would have an injurious effect on the adhesion, on account of the polish the steel might take; this mistrust became still stronger, when cast steel was applied to the rails also. But as we have already pointed out (I, 355) it has not been confirmed by lengthened experience of the lines on which low speed engines run, and where of course a great amount of adherence is utilised, such as those that cross the Jura, the Appenines, the Brenner, the Semmering, etc., etc.

This is what should have been expected For the rails, only *Bessemer* (or *Martin-Siemens*) steel is employed, which from its small dose of carbon, is rather cast wrought iron than cast steel (I, 358). As to the tyres of crucible cast steel, such as those of *Krupp*, the *Bochum* works, *Naylor*, *Vickers* and so on, they contain, similarly, a very small proportion of carbon. Although they may acquire from the fact of being run over a

certain temper, and sometimes great durability, the adhesion is in no way affected thereby.

§ III. — Influence of the velocity and of the amount of contact.

206. *Influence of the velocity.* — *Experiments of M. J. Poirée.* — Experiments on adhesion, and particularly the deductions to be drawn therefrom, are delicate; the results are modified by numerous elements; and the very ones of which the influence wants measuring, are often difficult to define with the necessary precision. Thus the terms: *rails dry*, *rails damp*, *rails wet*, have not an absolute enough signification always to indicate the identical state, especially in the hands of different observers.

The laws ordinarily admitted for friction, and especially for that in question, are empirical and true only, for and within the limits of the experiments from which they result. Thus the independence of the friction relatively to the extent of the surfaces in contact, and to their relative velocity, is pretty accurate only when these two elements vary but little.

The influence of the velocity, particularly, was established as far back as 1851 by the late M. *J. Poirée* (*), who operated in the same way as did afterwards M. *Bochet*: a ballast waggon more or less loaded, and having all its wheels skidded, was drawn by a locomotive, by the intermedium of a dynamometer placed in a large case, which entirely shielded the waggon, so that the resistance of the air entered but for a small part in the readings of the instrument. The experiments were made on a straight line, and on the level. Two markings were made simultaneously: one every five seconds, the other at each of the telegraph posts, the distances of which were unequal, but had been carefully taken. Laying down these markings on a diagram, the effort of traction, that is to say the sliding friction in uniform movement, and the velocity were given. But this mode of observation brings in a cause which may modify the results: that is the heating of the tyres under the influence of long continued sliding, a fact which does not occur under ordinary conditions, the limit of adhesion not being reached, or at least only so accidentally, when the engine slips.

(*) *Annales des Mines*, 5th series, vol. XIII, 1868, p. 271.

Experiments of M. POIRÉE (*Extract.*)

STATE OF THE RAILS.	DISTANCE for which the velocity and the draught remained constant.	VELOCITY feet per second.	RATIO of the draught to the weight.	OBSERVATIONS.
	feet.	feet.		
Very dry	1640	15,89	$\frac{1}{4,8}$	
	2625	25,59	$\frac{1}{5,6}$	
	984	32,81	$\frac{1}{6}$	
	5249	46,02	$\frac{1}{6,9}$	
Do.	984	25,92	$\frac{1}{4}$	
	984	42,65	$\frac{1}{4,5}$	
	3281	59,05	$\frac{1}{4,9}$	Bearing springs free.
	1312	75,18	$\frac{1}{5,3}$	—
Wet	3281	28,87	$\frac{1}{9}$	Vertical oscillations of the body very perceptible.
	2461	63,34	$\frac{1}{12}$	
Dry but having been wet in the morning	1312	19,68	$\frac{1}{4,8}$	
	1312	26,25	$\frac{1}{5,3}$	
	1476	29,53	$\frac{1}{5,5}$	
	1640	40,03	$\frac{1}{6}$	
	2230	65,68	$\frac{1}{7,3}$	
	1640	29,53	$\frac{1}{5,9}$	
Dry	984	23,74	$\frac{1}{4,8}$	
	2789	35,43	$\frac{1}{5,6}$	Springs fixed.
	3117	51,50	$\frac{1}{6,3}$	
	4265	65,62	$\frac{1}{7\cdot3}$	
Dry	2625	28,87	$\frac{1}{6}$	
	12,796	50,70	$\frac{1}{7,3}$	(After experiments.)
	3937	65,62	$\frac{1}{8}$	
	3937	72;18	$\frac{1}{9}$	Springs free.
Dry	1476	16,40	$\frac{1}{5,8}$	
	2230	29,53	$\frac{1}{6,3}$	
	1476	52,49	$\frac{1}{7\cdot3}$	
	10,827	62,83	$\frac{1}{8,4}$	

The diminution of the friction, when the velocity increases, is thus well marked.

It will be remarked: 1. that, contrary to the results obtained by all other experimenters, the friction was, at the same velocities, much less on wet rails than on dry ones; perhaps they were damp rather than really wet; 2. that the influence of the suspension appears to be nothing, contrary to the observations or rather the deductions of Mr. *Wood* on the subject.

M. *Poirée* made in 1856, an other series of experiments, but in a different way, because it was the question then of a special point, that is to say of appreciating the efficiency of the skid brake of M. *Cochot*. This brake consisted, especially, of an iron shoe, which a catch let fall in front of each of the wheels, and upon which the wheel mounted, transforming thus, almost instantaneously, the vehicle into a sledge. A goods waggon, loaded with a given weight was run up to a given speed by a locomotive, which could be unhooked at any moment. The uniform velocity being well established and measured, the catch and the coupling were both let go at the same moment. The engine ran off rapidly in front of the waggon, which lodged on the skids, and rapidly lost its speed. The distance run to slipping was measured, and the mean value of the coefficient f deduced therefrom.

Experiments on a waggon with Cochot's brake. Weight of waggon: 7tns,96.

STATE OF THE RAILS.	VELOCITY.	DISTANCE RUN before stopping.	COEFFICIENT calculated.	OBSERVATIONS.
	feet per second.	feet		
(Experiments of the 21th of May.) Damp weather, but rails pretty dry	21,85	49,20	$\frac{1}{6,7}$	
	26,54	85,30	$\frac{1}{6,9}$	
	36,45	155,84	$\frac{1}{7,7}$	
	46,85	308,40	$\frac{1}{9.2}$	The waggon gets down of the skids and rolls along for an instant.
	63,07	597,12	$\frac{1}{9,9}$	
	72,90	754,6	$\frac{1}{9,3}$	
(Experiments of the 24th of May.) Rails becoming wet	15,62	26,25	$\frac{1}{7,1}$	
	27,33	82,02	$\frac{1}{7,3}$	Doubtful.
	54,66	449,49	$\frac{1}{9,9}$	
	68,34	754,6	$\frac{1}{10,6}$	Strong head wind.
(Experiments of the 27th of May.) Rails dry	23.42	45,93	$\frac{1}{5,4}$	
	38,58	167,04	$\frac{1}{7,2}$	
	82,02	892,40	$\frac{1}{8,5}$	

Here again the influence of the velocity is clearly seen. It comes out no less evidently from M. *Bochet's* experiments, already referred to. But this fact can no more be construed into a general law for friction, than the inverse law be deduced from that other well known fact, that the tendency of the axle journals to heat, increases, every thing equal else, with the velocity; the increase, with the velocity, of the work transformed into heat, being in no way incompatible with a certain diminution of the coefficient of friction.

207. *Influence of the extent of the surface.* — In the above experiments of M. *Poirée*, who also experimented on waggons with their wheels skidded, the distance run up to the stopping of the waggon, was always greater, all things besides equal, in the case of the waggon sliding on *Cochot's* slides. It is necessary only, in order to render a comparison of the figures possible, to make a somewhat uncertain correction, that is to say, to deduce from the distance run by the ordinary break-waggon, the distance run from the moment of the signal, to that of skidding, which is not in that case instantaneous as with *Cochot's* skids.

The independence between the friction and the extent of the surface of contact, is only then true approximately, and the coefficient increases when the surface of contact diminishes.

According to the after experiments of M. *Bochet*, the relation between the coefficient and the surface would be more complicated. The surface at first large enough, diminishing, the coefficient would first decrease down to a certain minimum, whence it commences to increase.

208. In discussing the first series of M. *Poirée's* experiments, M. *Bochet* succeeded in representing their results pretty correctly by the following expressions, in which V is the velocity in feet per second (*):

1° On very dry rails........... $f = \dfrac{0{,}31}{1 + 0{,}00915\,V}$,

2° On wet rails............... $f = \dfrac{0{,}14}{1 + 0{,}00915\,V}$,

3° On moderately dry rails...... $f = \dfrac{0{,}22}{1 + 0{,}00915\,V}$,

the numerator going down to 0,010, and perhaps even to 0,008 under the influence of fog, hoar frost, dry leaves, and so on. But later, as we have

(*) *Annales des Mines*, 5th series, vol. XIII, 1868, pp. 28 and following.

seen (202) M. *Bochet's* experiments own led him to quite different conclusions, as regards the influence of the degree of dampness on the rails. He also became aware that his results could not be represented by a simple numerical function of the velocity, and that they could only be so by an expression of the form: $f = \frac{k - \gamma}{1 + aV} + \gamma$, but in which none of the coefficients is constant; a varies, little it is true, under influences which could not be made out(*), while k and γ are functions of the nature of the rubbing surfaces, of that of the unguent, if there is one, of the degree of polish of the surfaces, and of the pressure per unit of surface. The value of k, always superior to that of γ, is ordinarily comprised, for polished iron, between 0,20, and 0,36, but goes down sometimes as low as 0,17, and even as 0,12.

The real law is certainly very complicated, and the more the series of experiments extends, the more the complication due to the influence of the divers elements, partly unknown, becomes manifest, and renders the establishment of an empirical formula impossible.

M. *Hirn* is inclined to think that direct friction, that is to say without the interposition of any unguent between solid bodies, follows simply the laws of *Coulomb* and *Morin;* and that the effect of any unguent is to greatly complicate these laws, by bringing in the influence, not yet defined, of the extent of the surfaces in contact, and of the velocity.

209. The fact best established is, definitively, the small diminution, of the rest, of the coefficient f when the velocity increases. This fact has moreover, no injurious influence on the traction, the effort exerted by an engine supposed to produce always the same amount of work, diminishing when the velocity increases, in the inverse ratio of that velocity, that is to say according to a law much more rapid than f.

210. *Absence of special friction at starting.—M. Bochet's experiments.* — It is well known that the old experiments testified, in the case of several bodies, to the existence of a special friction at starting. M. *Bochet* tried if it is the same with regard to iron, under the conditions presented by rails and wheels. The difficulty consists in the condition of absolutely preventing the intervention of inertia, which would completely upset the results; the precise point must be seized, at which the resistance is overcome, but

(*) *Annales des Mines*, 5th series, vol. XIII, 1868, pp. 111, 112, and 113.

without appreciable velocity. M. *Bochet* proceeded by attaching the sledge-waggon to the engine by means of a long cable, which the engine gradually stretched until the waggon was just on the point of starting. The regulator was then shut, and the wheels of the engine were pinched on with bars, care being taken, before taking out the bars that had moved the engine a little bit, to put in others, so as to prevent the reaction of the cable from dragging the engine back. The cable was thus progressively stretched, with great deliberation, up to the point when the actual starting of the sledge took place.

For iron, there was never any special friction at starting; the effort strictly necessary for starting, was always the same as the friction during running, at a very low uniform velocity. If then its diminution, when the velocity increases, arises from the fact that the asperities on the surfaces take less hold, and consequently the impression of the surfaces on each other, becomes less and less marked, we ought to conclude that this mutual holding on of the asperities, should attain its limit in a very short space of time, seeing that it is as complete, when the surfaces have a relative movement (very slow it is true), as when they have been in contact for a long time at rest. It is not the same thing for other substances, wood for example. For that, the friction at starting exceeds very considerably the friction in movement, even at the lowest velocity.

MM. *Vuillemin*, *Guébhard* and *Dieudonné* seem to admit a special value for the adhesion at starting.

"In practice," they say, "the coefficient of $\frac{1}{5}$ may be admitted as the adhesion at starting."

But in this, there is confusion between adhesion *utilised*, and the limit of adhesion, the friction.

"Starting," they go on to say, "being always done with the reversing lever right over, at each time of starting, the limit of adhesion is pretty nearly approached, and the coefficients then found, are higher than those obtained during running (*)."

Which amounts to saying simply, that the effort of traction, is, in practice greater at starting than in running. As to the adhesion, it is subjected to the same influences, to the same variations at starting, as in running; and in any case, it is difficult to understand upon what the authors of the

(*) Paper already referred to, p. 64.

paper found the constant value assigned to the first, of $\frac{1}{5}$, while in the second it varies, according to them, from $\frac{1}{5}$ to $\frac{1}{9}$ (203).

211. *Resistance of trains to starting.* — Let us anticipate a little, a subject treated of farther on, the resistance of trains, to note down an observation which naturally occurs here.

From the absence of special friction at starting, in the case of iron, it must not be concluded that there is no special resistance at starting, for a vehicle or a train in motion. It is scarcely probable that it should be so for one of the elements of that resistance, that is to say, the rolling friction. But it may be quite different for the sliding friction, brought in this case on to the journal, exerting itself between two bodies, one only of which is iron, and with the interposition of a lubricating medium, the state of which may be modified by a greater or less amount of rest.

However the existence of a special resistance at starting is all but proved. Examples are quoted of wheels remaining fixed, in winter, and not commencing to turn until after a certain time; but a few facts of this sort, were they well authenticated, would only show that the axles were very badly lubricated.

According to the experiments of the engineers of the Eastern of France (*), the resistance of a train at starting would appear to be much more considerable than its resistance when running at a uniform velocity, even considerable; but what these engineers have measured, is not the resistance at starting, it is the effort necessary to *start* the train in the purely practical sense of the word, that is to say, the sum of the resistance properly so called, and of the force of inertia corresponding to the *usual* acceleration. It is thus they found, for passenger trains, an effort, per ton, twice that for goods trains, which arises quite simply as they say " from the couplings in the former being tightened up more, and from the speed having to be got up quicker."

We should find in this way, for goods trains, a resistance still less than that which was obtained, if slower starting were allowed. It is desirable, unquestionably, to be aware of the force necessary practically for starting, neither too slowly nor too suddenly; but we should not obtain thus the measure of a definite determined force; to obtain that, and to know whe-

(*) Paper referred to above, p. 30.

ther there is or not a special resistance at starting, the effects of inertia must be, as M. *Bochet* did, entirely obviated.

212. It needs scarcely be said, that engineers who have to design an engine and to fix its adherent weight, in such a manner as to satisfy the equation of condition, take for f a number, such as practice shows, to be small enough, without preoccupying themselves with the laws of friction, so complicated, and so little known In these countries $\frac{1}{7}$ (0,14) is ordinarily adopted, a figure with which slipping is rare, at least on a main line. In Germany $\frac{1}{20}$ and $\frac{8}{20}$ are admitted to be the limits, and $\frac{1}{9}$ as the ordinary value (*).

In tunnels, the coefficient hardly ever attains as high a value as in the open air. It keeps therein, to a pretty constant figure, often equal to its minimum value in the open air, and determined by divers causes; the length of the tunnel, the amount of infiltration, and the activity of the traffic. The greater the amount of traffic, the more steam is precipitated on the rails, and keeps them covered with water in the vascular state, the most unfavourable to adhesion.

This influence is such that it should always be taken into account in deciding the definitive section of the line. Without creating serious difficulties for the working, or using the power of the engines only incompletely, in a tunnels of a certain length, gradients cannot be admitted to steep as in the open, so that the tractive power may not be diminished by the reduced adhesion.

On the line from *Bologna* to *Pistoia*, for example, the inclination is one in 40, in tunnels as in the open. This is a mistake, but in no way owing to the engineers, upon whom it was rendered obligatory by the governments concerned in the project, before the establishment of Italian unity. It was impossible to keep below one in 40 in the tunnels, without going above that in the open, unless by lengthening the course of the line; and as one in 40 was an absolute limit, it was necessary to adopt it, and give up altering the section, which would have considerably improved the conditions of working. The evil is not great for those of the very numerous tunnels, which are short, but it is not the same thing for those of *Casale*,

(*) *V. Kaven, Vorträge über Ingenieur-Wissenschaften.*

Sante Momme, *Signorino*, and *Pitteccio* which are respectively 1,63, 1,69, 0,66 and 1,09 miles in length.

This example proves that the decision of such questions ought to be left to the engineers. The reduction which is desirable to be made in the inclination in tunnels, can only be determined in each particular case, and is always somewhat uncertain. Thus between *Pontedecimo* and *Busalla* (line from *Turin* to *Genoa*) the engines slip more on the incline of one in 31 in the Giovi tunnel than on the inclines leading up to the tunnel, which are one in 28,5. It would have been better to have stiffened the gradient a little in the open, so as to reduce it in the tunnel, where the effort of traction cannot exceed $\frac{1}{10}$ of the adherent weight, and that with great recourse to sand; of which we shall soon speak (216). In the *Hauenstein* tunnel (Central Swiss) this effort can go as high as $\frac{1}{8}$ of the adherent weight, always however with the help of sand, in place of from $\frac{1}{6}$ to $\frac{1}{7}$ in the open.

213. *Returns of slipping.* — If the transmission of the effort of traction by adhesion is valuable on account of its simplicity, if it is the sole practical means, beyond a few extreme cases which we shall examine farther on, it is certainly not exempt from drawbacks. It necessitates, when the conditions of climate are unfavourable, a considerable reduction in the loads of the engines, which are then incompletely utilised. If, in spite of this reduction of load, slipping persists, the regularity of running is interfered with, and the machinery, tyres and rails all pay a heavy penalty.

The supply of water is often wasted in this improductive and destructive work indeed, and requires the use of an additional engine. It is of great use to study directly, in the daily practice of traction, all the circumstances in which this serious obstacle to the regular running of trains, arises. The following service order of the Eastern of France (November 1867) prescribes the establishment of returns of slipping, the form of which we give here. It is a useful measure, which it would be very desirable to see generally carried out.

The slipping of engines often arises from local causes which it would be possible to get rid of, and which it is of consequence to study.

With this view, the running sheds will be provided with forms, called *returns of slipping*, numbered 500 in the printed forms of the locomotive department.

A return will be made out every time that a train has met with any slipping of importance.

The first part of the return is intended to give information of the circumstances connected with the engine, under which the slipping occurred. It must be filled up and signed by the driver, then checked by the running foreman. The latter will see the return forwarded to the superintendent, not more than six hours after the arrival of the train.

The second part of the return is intended to furnish information of the permanent way, at the part where the slipping took place. It will be filled up and signed by the divisional inspector; who must point out in the column " observations " the means he has taken or proposes to take, to put a stop to the slipping.

The return ought to be forwarded within twenty four hours to the engineer of the line, who after having noted it, will send it on to the locomotive superintendent.

Every month an abstract of the returns of slipping will be forwarded by the locomotive superintendent to the engineer of the line.

EASTERN LINES

COUNTERFOIL

of the

Return of slipping.

No

No of the Train :

DATE :

187 .

No of the engine :

OBSERVATIONS :

EASTERN OF FRANCE RAILWAYS

TRAIN NO

of the 187 .

Return of slipping No .

NUMBER of the engine:

NUMBERS.	DISTANCE by the mile posts of the slippings.	TIME LOST by the slippings.	STATE OF THE ATMOSPHERE (wind or calm, fog, frost, rain fine or heavy).	LOAD of the train in units of 10 tons.	NUMBER of waggons.	OBSERVATIONS.
1						
2						
3						

Signature of the driver, *Signature of the foreman,*

NUMBERS.	RISING gradients.	MINIMUM radius of curves.	EMBANKMENT cutting or tunnel.	NATURE and state of the ballast.	STATE of the permanent way.	SYSTEM of rails.	PROXIMITY of woods.	OBSERVATIONS.
1								
2								
3								

Signature of the divisional inspector,

§ IV. — Means of increasing the adherence with the same load on the driving-wheels.

214. *Driving wheels with a groove.* — P being the total weight of the engine, $\frac{P}{n}$ the load on the driving wheels, the adhesion is $f\frac{P}{n}$. P is as small as the conditions of dynamical power and solidity of construction will permit; n is at least equal to 1, and cannot often be less than 2, or say 2,5 $\frac{P}{n}$ being given, it is f that must be operated on, in order to increase the adhesion.

There is indeed a theoretical method of increasing, as it were indefinitely, the adhesion for given values of f and $\frac{P}{n}$: it is to give the head of the rail the form of a truncated prism, entering into a groove in the driving-wheel (Pl. XVIII, *fig.* 19). There is thus, between the load π of the wheel and the normal reactions t, on the edges in contact of the rail and the groove in the wheel, the relation $t = \frac{\pi}{2 \sin \alpha}$, and the adhesion is $2ft = \frac{f\pi}{\sin \alpha}$.

This contrivance seems to have been pointed out for the first time by M. *Crelle* in a paper published in 1846. Wherever the ordinary adhesion is sufficient, the wheel runs on the rail by the cylindrical surface of the top of the groove, which is considerably wider than the rail (*fig.* 20). When a supplementary adhesion becomes necessary, the head of the rail gradually widened out to more than the inside of the groove, only then takes the wheel by its sides (*fig.* 19).

But in order that this local widening out of the rail should be compatible with the free running of waggons over the rail, the wheels thereof would have to be widened also; which would result in the establishment of a special rolling-stock unable to run through ordinary crossings, without taking into account the increase of expense, and the exaggeration of the play in the road (I, 199) for the waggons wherever the rail was not widened, while this play would disappear, on the contrary, for the engine; the grooved tyre should besides be only applied on one side of the engine; with grooves on both sides, the small inevitable irregularities in the gauge of the line would be sufficient mostly to prevent one of the grooves from taking on to the rails by its two edges. The wheels of one side only then would have grooves, the opposite wheels having ordinary tyres, and run

ning on the head of the rail, which would reduce by half the gain in adhesion; but both rails would have to be conical, upon single lines, on account of the turning of the engine, and on double lines because running in the reverse direction is at times necessary thereon.

The idea of wheels with a wedge-shaped groove, which M. *Crelle* did not thoroughly go into, was revived some years later by an Italian engineer, M. *Minotto* (*), who was led to give up the adhesion on the side rails, and to cause a central wheel with groove, to work into a central rail, bearing necessarily a considerable portion of the load.

The wedge can be, and has in fact been applied to the transmission of movement by simple friction; but the applications are limited to rapid movements of rotation, with effort of small intensity. For railways, as natural as may seem the idea at first sight, it appears very difficult to make any use of it. With ordinary tyres, the central impression of the two bodies increases the area of the bearing of the wheel, and thus spreads over the pressures, but without any sliding resulting, the elements in contact separating normally at the surface. With the grooved wheel, this movement is parallel to the zone of contact, so that the elements of the groove which were at the origin in contact with the inclined sides of the head of the rail, rest thereon during a certain travel, and slide on them. From that arises a considerable increase in resistance and wear, effects which can only be lessened by a convexity necessarily very limited, as it would be very soon worn down. Again, the faculty of displacement of the wheel transversally to the rail disappears; and with it the good effects of the conicity of the tyres, combined with the play in the road. An increase of adhesion obtained at this price is scarcely admissible.

A well known English engineer, Mr. *W. Bridges Adams* declared himself a partisan of this expedient, with $\alpha = 45^\circ$. He fully admitted the increase in wear and tear; but when, said he, an exceptional effort of traction is necessary, we must fain put up with sacrifices of some sort. That is true; but the whole thing consists in making the compromise that presents the fewest disadvantages, and here it is not only a question of wear and tear, but also of increase of resistance, which reduces the power of the engine, and of the expense of the central rail, unless that should be necessary from another point of view.

M. *Chaplin*, an English constructor, recently tried grooved tyres to four

(*) 1. *Su i vantaggi del Cuneo per accrescere l'aderenza*, etc., *Turin, J. Favale* 1852; 2. De l'engrenage à coin. — Do. — Do., 1853.

wheeled contractors engines, intended for working on stiff gradients. The wheels on both sides having grooves, it was necessary to make special provision for the engine to yield to the small inevitable variations in the distance between the rails. The wheels are free to slide on the axles, and thick india-rubber washers on the axles, control this play.

The success of this attempt is very doubtful. If the wedge gearing were really practical, there would be plenty of occasions to take advantage of it for industrial purposes, and its application would not be restricted to a few unimportant instances. Beyond the transmission of small efforts at a high speed, the principle is admitted to be inapplicable. In transmission by cables, on inclined planes for example, where the effort of traction has to be transmitted by the simple friction of the endless rope on the drums, conical grooves have been tried for obtaining the necessary adhesion, with a reduction of the number of turns, or the balance weight. But this did not answer because, independently of the increase of resistance, the wear of the cable is much more rapid. It would be exactly the same for rails and tyres.

215. The disadvantages found to attend the use of cables can be avoided by having recourse to an ingenious but complicated artifice, that is to say the movable jaws of *Fowler's* pulley, successfully used for steam-ploughs, and more recently for towing with a cable instead of a chain over toothed wheels. The jointed jaws with which the pulley is provided, strain the cable by exerting on it, lateral pressures proportional to the pressure it itself exerts on the bottom of the groove, and such, that, on each side the resultant of these forces passes through the axis of rotation o, of the jaw. (Pl. XVIII, *fig.* 21).

R being the resultant of the pressures of the cable on each of the opposite jaws, the adhesion developed on the pair exceeds $2f$R, the friction on each jaw being proportional to the sum of the reactions between them and the cable, a sum which is superior to their resultant. Let the difference be neglected. $\frac{p}{2}$ and π being the components of R, one along the radius of the pulley, the other at right angles thereto, and R passing necessarily through the axis of rotation, we have :

$$\pi h = \frac{P}{2}\,l; \quad \text{whence} \quad \pi = \frac{P}{2}\frac{l}{h}, \quad \text{and} \quad R = \sqrt{\pi^2 + \frac{P^2}{4}} = \frac{P}{2}\sqrt{1 + \frac{l^2}{h^2}}$$

and the adhesion is $fP\sqrt{1+\frac{l^2}{h^2}}$, instead of fP, the value which it would have if the cable were simply wound round a cylindrical rim.

It can be increased to as great an extent as may be required, by giving a

suitable position to the axis o, and consequently suitable values to l and h, but the ratio $\frac{l}{h}$ is limited; the pressure $\frac{P}{2}\sqrt{1+\frac{l^2}{h^2}}$ on the axis o must not be excessive.

Whenever the cable separates itself from the bottom, the lateral pressures disappear, as does the pressure on the bottom, which gave rise to them. But the application of such arrangements to the driving wheels of locomotives, evidently could not be entertained; they are besides, even for simple pulleys, inadmissible at velocities which locomotive wheels always exceed.

216. *Use of sand.* — As besides the adhesion is in general sufficient, and only fails accidentally, the question is far less to increase it by permanent mechanical expedients, than to remedy its temporary insufficiency, by arrangements also temporary. When the value of f falls below the ordinary figure which has served as the basis in establishing the relation between the effort of traction, and the adherent weight, it is f that must be acted upon, by artificially raising its value. When there is hoar frost, sand is thrown on the streets; in the same way, sand is thrown on the rails when the engine tends to slip, whatever may be the cause thereof.

It is frequent, especially: 1. at starting; 2. on long rising gradients; 3. in tunnels. In the first, because in order to start quickly, the effort of traction must be very superior to the resistance of the train in uniform movement (198); in the second case, because if the engine can by reducing its uniform velocity develop the increase of effort of traction required by gravity (an increase reduced, by the way, by the diminution of the resistance proper of the train, which results from the diminution of the speed), the adherent weight, which was sufficient on the level, with the rails in the same state, may no longer suffice for the effort so increased; in the third case, with the same gradients of course, on account of the permanent dampness generally occurring in tunnels.

The seasons have a marked influence on adhesion. Under those climates such as our own, which are subject to damp, slipping is frequent, above all in autumn. To this influence is added in passing through forests the aggravating cause already indicated: the falling of leaves, which wet the rails, and sticking thereon form when crushed under the wheels, a sort of organic unguent. For a long time but little employed, sand has become now-a-days, a very important and indeed an indispensable auxiliary. On certain lines with steep gradients and great traffic, in the Giovi tunnel for example, it is employed in such quantities, that the line has frequently to

be swept clear of the excess of sand that has accumulated thereon from the traffic. At the crossing of the Semmering, the annual consumption of sand goes as high as 2300 c. yds.

It serves not only, besides, to increase the adhesion for traction; it is also a valuable element of safety, because it increases the action of the brakes on the wheels. A driver who whistles for the brakes in the presence of pressing danger, ought never to omit letting down sand at the same time, to increase the efficiency of the brakes, not only of the engine and tender, but also of the carriages. Sand also allows the loss of time in stoppages to be reduced; thus the "North London", a small line to which we shall have occasion to return, may be cited among those who make use of sand most largely, not only on account of its gradients, but also because of the frequency of its stoppages. Each engine uses a ton and a half a week of it; and the necessity of starting sharp, enters for a large part into this figure.

The engines of the London "*Metropolitan*" have sand tubes for working in both directions, which is necessary in effect, for engines which have, as these do, to run very frequently backwards.

This double injection is besides very useful also in starting when shunting; it should be applied to all goods engines, as these have often great difficulty in shunting their long trains in station operations, particularly in bringing them into the siding, case in which time is often very precious.

It is clear that sand, which renders such service, increases at the same time the resistance of the waggons in running along the rails; but this is a comparatively slight drawback.

The sand ought to be siliceous, as hard as possible, of medium coarseness, and without the slightest mixture of clay. On the *Central Swiss* line, it is sifted so as to exclude all the grains of more than 0 in, 31 in size.

The slag from iron furnaces, granulated in water by the process of M. *Minary*, and employed with success for ballasting, as we have seen (I, 175), suits equally well. The *Méditerranée* makes great use of this, and prefers it to the best natural sand.

The sand should be distributed on the rails regularly, and by measure. Excess is injurious; there ought only to be so to speak one single layer of grains, deposited by a small tube opening in front of the driving wheel, quite close to the rail. The sand runs out generally by the effect of gravity as in the common hour glass. But the conditions of homogeneity of the sand, very fine besides, used in that apparatus, are not found in the same degree, and are moreover less necessary in that employed on railways. Thus, spontaneous running out of the sand, effected by simply uncovering

the orifice of the tube in the reservoir, is sometimes irregular and intermittent, in spite of the influence of the jolting of the engine, which tends to clear the tube. This irregularity increases still more if the sand is damp: now-a-days care is always taken to supply it dry, and to keep it so.

For certain kinds of sand even when dry, spontaneous running out is irregular; thus there is employed, on several lines, a mechanical distributor, formed of a helicoidal plate twisted round a horizontal axis (Pl. XVIII, *figs.* 1 to 6), and which, when it is turned, pushes before it a column of sand, just as a screw pushes on a movable nut. The distribution is then perfectly regular, and the driver regulates the expenditure as he requires, by turning the handle fast or slow.

On some lines, on the "Eastern of France", for example, the two methods: spontaneous running out, and mechanical distributor, are in use; which is explained by the different sorts of sand to be found along the different portions of the lines.

The sandbox of the *Eastern of France*, represented by *figs.* 1, 2, and 9, costs filled in place, with cast-iron screw, and brass-tubes, £ 5.

The distributor requires the constant action of the driver or fireman; a slight disadvantage when it is only a question of an accidental tendency to slip, or to accelerate the starting, but rather serious when it comes to turning the handle for several miles. Such is the case on the "Central Swiss", at the crossing of the Jura, which presents on the northwest slope between *Sissach* and *Laufelfingen*, an incline of one in 46 for six miles, and on the opposite slope, from *Olten* upwards, gradients of one in 40, for 3,76 miles, then one in 37 in the great tunnel of Hauenstein, 1,55 mile long, always damp, and in which slipping has constantly to be struggled against. The ordinary sandboxes gave inferior results, from their irregular action. To be sure that there was sand enough, it was often necessary to have an excess, not only useless but injurious. Led thus to adopt the distributor, imitated from the sowing-machine, M. *Riggenbach* tried to add thereto a gear taking its movement of rotation from one of the axles (Pl. XVIII, *figs.* 7 and 8), and doing away with a troublesome operation for the driver. The shaft of the distributor is driven by a level-cog-wheel, which receives the movement of an endless screw v, on the axle E; the axis a carrying the spur pinion e and the wheel ρ is supported by a socket mm, which by the lifting gear $\alpha\beta\gamma l$ can be worked so as to put the wheel ρ in or out of gear with the endless screw v. But this is all far too complicated; the velocity of rotation cannot either, be varied at will; tus thhe working by hand has been returned to, keeping the

special distributors on each side of the engine; the two helices are contrary ways on the same shaft (*figs.* 3 to 6). The apparatus works very frequently on the inclines leading up to each end of the tunnel, and continuously in the tunnel itself. The sand is very uniformly distributed in a fine stream, and the total amount used is not the one quarter of that of the ordinary sand-box, working by jerks, and depositing every here and there on the rails, little heaps of sand, which the engine with difficulty got over.

Excess has, besides, another serious inconvenience; a part of this sand in excess, adheres to the wheels, and is afterwards blown by them into the machinery, to the great increase of wear and tear.

The price of this apparatus varies from £ 14 to £ 18 (fitting not included), according to the facility which it can be adapted with to the different types of engines.

217. *Drying the sand.* — On the *Jura* industrial line (from *Neufchâtel* to *la Chaux-de-Fond*) on an incline of 1 in, 37 where the use of sand is almost constant, the agglomeration on account of the damp, and even freezing during the winter, created difficulties which were incessant at the outset, but which were got rid of by drying the sand, spread in layers of from 2 ins, 40 to 3 ins, 40, on a iron plate heated over an open fire.

Constant stirring was required; the price of this roasting amounted to as much as 26 shillings per ton.

M. *Grapinet* (*) substituted in 1869, for this defective operation, a much more expeditious and economical method. The apparatus is shown by *figs.* 15 to 18, Pl. XVIII, which explain themselves. The exterior tube, of cast-iron, T, 0 ft, 98 in diameter, plays the part of flue, and concentrates the heat on the inside tube *t*, inclosing an Archimedean screw T, moved by a small fall of water, or at need by a man, and which determines the progression of the sand. The steam passes off through a series of holes made in the upper part of the tube *t*, and is drawn off by the chimney; the sand perfectly dry, falls into the sieve C, which separates out the grains which are too coarse G G. The price of the drying and sifting becomes by this means reduced to 2s, 6 d.

Under ordinary conditions, the drying of the sand is only necessary during bad weather, and for that purpose either a small portable sheet-iron *cask* is used as on the "Midi" and the *North London*, or simply, as on the

(*) *Annuaire des anciens élèves des Écoles des Arts et Métiers*, 1867, p. 122.

" Méditerranée " lines, sheets of iron placed over the grates employed in winter for heating the sheds.

The position of the sand-box on the boiler is sufficient to keep it dry, which is done still more effectually by placing that receptacle in the bottom of the chimney itself, as M. *Forquenot* has done for some of the engines of the " Orleans " lines. On these lines the mechanical distributor is not used. The slide, worked by the driver, uncovers a triangular orifice, in such a manner, that to a very small amount of displacement, corresponds a very reduced opening for the sand to pass through ; the capacity of the reservoir is ordinarily about 3 cub. ft, 5.

218. — Sand renders, altogether, great service on lines with steep gradients, and on short lines where the stoppages are frequent. It is, on the lines of great traffic and trains at high speeds, an element of safety too much neglected. Its nature, its state, the manner in which it is used, and its effects have not been besides studied however as they deserve to be. No precise experiment appears to have established the exact measure of its action. According to some English engineers, sand of a suitable nature, and suitably employed, without excess moreover, could compensate for atmospheric influences, and could maintain the adhesion at a sensibly constant figure: that certainly is going too far. Sand is a useful palliative, but not an absolute remedy against the variation of adhesion.

Its use requires, at the same time, some precautions in the interest of the appurtenances of the permanent way. An order of the 8th. of May 1864, by the locomotive department of the *Méditerranée* lines, stated :

" The sand which the engines let down on the points and crossings, may prevent the points from closing properly, either when they close by themselves after the passage of engines which go through, not facing, or when the pointsman lets them go, after having worked them, to work something else. To avoid this inconvenience, drivers are prohibited from opening the sand box of the engine, or to leave it open while passing over points, or to let sand down on the points in any manner whatever. "

The use of sand cannot, however, be prohibited in stations, where the rails are very subject to get oil on them from engines either running or standing, and where startings are continual ; only as far as regards the appurtenances of the permanent way, the pointsmen might have the distribution of the sand, as they are in a better position to do so with the needful precautions, than the drivers. A general order of the system of lines already cited (n° 14, art. 180), modifying the preceding order, only requires the points-

men to do this in the case of engines, of which there are few now-a-days, which have no sand-boxes. It is thus drawn up·

"When the state of the rails renders the starting of the trains difficult, on the way, or shunting, and if the engines are not provided with sand-boxes, the pointsmen must themselves throw sand on the rails, in front of the engines, on their passage into sidings or through crossings, carefully avoiding to allow pieces of gravel to get in between the parts. In these circumstances, they ought to make sure after every train has passed that the points continue to act properly."

At the period when the use of sand was still in its infancy, pieces of coarse gravel were often employed, placed by hand on the rail; there bulky pieces, stored like the sand in a simple box placed at a certain height, indeed only on the frame, could scarcely in their fall, have stopped on the rail.

Contrivances, sometimes ingenious, were proposed for checking their velocity and keeping them on the rails; but the inevitable complication of these apparatuses would only have been warranted by real advantages attached to the use of coarse gravel; while, on the contrary, there are no such advantages. Coarse gravel only acts usefully when it has been crushed by the wheel, and until then it is nothing more than an obstacle to the movement.

219. *Magnetic adhesion.* — The idea of utilising magnetising by currents and magnetic attraction, occurred long since. It is in fact seductive.

Thanks to it the equivalent of an increase of load, without the inconvenience thereof, without increasing the deflection of the rails, would be obtained. A score of years since, the late M. *Nicklès* and MM. *Cassal* and *Amberger* made some trials at *Paris* in this direction. The magnetising of the wheel was produced by a coil of elongated shape, surrounding its lower part, and placed as near as possible to the rail. This position of the coil presented no risk; it was sufficient to arrange it so that if it fell off could not cause the engine to run off. What kept railways engineers from interesting themselves in this experiment, was that success, without being of no importance, would be purchased at the expense of too much complication. Adhesion being sufficient under the ordinary conditions of state of rails and of speed, and the sand reducing in the simplest manner its accidental insufficiencies, it could scarcely be expected that the engine already complicated enough, could be saddled with a whole concern of physical apparatus : pile, coil, conductor, etc.

It is only for engines which require a great deal of adhesion, and the

wheels of which cannot well be coupled, that this expedient could receive any application; and then in the case of fully verified success, it might, sometinues, react favourably on the section itself of the line. But we are by no means at that point. In general, there would be no grounds for seriously taking up this application, unless engines could be made very much lighter for the same power, than they actually are. Now if there be any progress that we can forecast, it is assuredly not that; besides the experiments made under my own eyes in the workshops of the *Lyons* lines, at *Paris*, gave completely negative results. The attraction, feeble enough while the wheel was still, under the influence however of the current from a powerful battery, rapidly decreased as the wheel turned round, and became almost nil at the normal velocity of rotation. Perhaps the coercitive force of the iron, too impure, did not permit the poles of the temporary magnet to keep a constant position in space, independent of the rotation of the wheel.

It appears that they have been more fortunate in the experiments undertaken in the United-States, on the *New-Jersey* railway. The engine was attached to a fixed point, the pressure in the boiler was raised until the wheels slipped: 1. the battery not being in action; 2. the circuit being closed. The increase of pressure necessary, gave the measure of the adherence obtained by magnetising the wheels; it is stated to have reached 40 per cent. However, these trials, which go back to 1860, do not seem to have been followed up, which makes their success appear doubtful.

§ IV. — Trials made with the object of substituting the adhesion of road-metalling for that of rails.

220. *Larmanjat's system.* — We should not dwell on this idea, if it had not been the object of lengthened experiment, very intermittent by the way, and if on the other hand, quite an unexpected amount of adhesion, of a nature to give a wrong impression of its real value, had not given it a sort of renown.

The principle consists in getting rid of the insufficiency of the adhesion on rails, by substituting for it adhesion on road metalling, or if required, on other substances.

From what facts, by what observations does M. *Larmanjat*, the inventor, deduce the benefit of this substitution? By what figure does he measure it? It would have been worthwhile to state.

Road locomotives utilise their power, it is true, running at a speed less than that of the slowest locomotives that run on railways. At first sight,

one might be tempted to conclude that the adhesion of the wheels on metalling is always much greater than the adhesion on rails; but the example of road locomotives proves nothing, because they are, by reason of the special requirements of their construction, much heavier than locomotives of the same power would be; adhesion often fails in their case also; as is proved by the attempts which we are about to deal with.

In an article inserted in the "Annales du Conservatoire des Arts et Métiers(*)", Professor *Tresca* states that a road locomotive of 8 tons, can develop as much as 30 horse power, "during a short distance", and as according to him, a railway locomotive "of 100 horse power" "weighs 40 to 50 tons", he concludes from this comparison, "that the construction of traction engines is almost as favourable as regards lightness, as that of locomotives". But this estimate of the relative weight of locomotives is, as we shall see, quite erroneous.

M. *Larmanjat* appears to have confounded two things essentially distinct: adhesion, that is to say, at the limit, the resistance to slipping, and the resistance to rolling. The latter is certainly much greater on metalling than on rails. The former, very variable at the same time, is perhaps sometimes greater, but certainly also sometimes less than on rails; so that what is increased, in effect, by the contrivance in question, is not the useful element, the limit of a friction which has besides not to be overcome, but the objectionable resistance, which has to be got over.

When the wheels of even a light cart, have sunk deeply into a compressible soil, a very considerable effort is required to start the cart. This is, in a somewhat exaggerated shape, what the principle of M. *Larmanjat's* starting point fundamentally comes to. It would be all very well, if it were a question, on an incline, of preventing the train from running backwards; but as it is a question of making the train run up, the net product of the contrivance, amounts to inflicting on the engine, the increase of effort corresponding to the greater compressibility, and want of elasticity of the rolling surface.

The idea is carried out in the following manner. The permanent way consists of only one rail; each vehicle, engine or waggon, has four wheels: two along the centre line, running on the rail, and two side ones running on the metalling. But the distribution of the weight, is inverse in the two classes of vehicles. In the engine, the two side-wheels are loaded as

(*) *Expériences sur deux machines routières de M. Lotz*, vol. VII, 1867, p. 407.

much as possible, seeing that the question is to get adhesion, and that the inventor attributes a great advantage in favour of metalling in this respect; in the waggon, on the contrary, the load is brought on to the longitudinal wheels, in order to take advantage of the less resistance on the rails; the side-wheels loaded by very flexible springs carry very little, $\frac{1}{3}$, or even only $\frac{1}{4}$ of the weight, their only object being to keep up, to stay so to speak, this tottering edifice.

The metalling becoming rapidly destroyed by the action of the driving-wheels, the author soon proposed to replace it by longitudinal timbers: this was so far a progress. There is only one step from that to another progress : the application of strips of iron to protect the longitudinal timbers; and that being an objectionable combination fully condemned, the substitution for them of iron rails. What then remains of the system, unless it be three rails instead of two?

221. The *Larmanjat* system found however a decided partisan, it might be said enthusiastic, in an engineer (M. *Belgrand*) who, in his own special way, has acquired just renown. In a report, presented to the "Council General" of a department, which had great publicity (*), this engineer expresses himself in the following terms:

"The friction of the driving wheels on the rails can be increased only by increasing out of measure, the weight of the locomotives, and it is thus adhesion enough is got to put the train in motion."

This opinion that locomotives are designedly made very heavy solely to give them the necessary adhesion, we shall find it come up more than once, and inspiring solutions of the question, not less unfortunate than this one in question.

"The steeper the railway-incline becomes", we read in the same report, "the greater ought to be the weight of the locomotive. To take gradients of one in 50, which are admitted on local lines, the engines must be very heavy even with a very small goods train; that is to say, very heavy rails, excellent ballast, very solid works, etc.; according to us" this is a difficulty which ought to cause the most part of the projects presented to be rejected."

This is all quite correct; only the author brings his case, not as he believes against the want of adhesion, but against the locomotive itself, against its principle.

(*) *Annales des Ponts et Chaussées*, 4e série, 1869, p. 500; *Journal officiel*, etc.

" It would be necessary," he goes on, " in order to establish railways under practical conditions, to considerably increase the adhesion of the driving wheels, with light engines."

Which would in effect be most desirable, of course, under the condition that these "light" engines had their dynamic power in accordance with the work they have to do. But afterwards the author adds :

".... M. *Larmanjat* has solved this problem in a manner as simple as economical: *he multiplies tenfold, at need, the adhesion of the driving-wheels*, by causing them to run on a metalled road or on longitudinal timbers; and at the same time, he reduces the force of traction to a minimum, by running the other wheels of the engine and those of the waggons, on an iron rail. "*With an engine weighing five tons, he can obtain as much and more adhesion, as with one of the heaviest engines of the Lyons line, weighing 40 tons " !*

".... M. *Larmanjat* produces with very small locomotives, weighing with their load, from 4 to 5 tons, sufficient power to take a train of 15 or 20 tons, up inclines, no longer of one in 50, but of one in 25 to one in 20."

As to speed, there is not whatever mention made of it.

Let us admit that M. *Larmanjat* has obtained a much greater amount of adhesion, say ten times greater, than the adhesion on rails.

Even were that so, where is then the new principle, which allows, as pretended, of such an enormous reduction in the weight of the engine with relation to its power, that is to say, to its heating surface? Is this engine not composed of the same elements as other engines? What is the reduction of weight permitted to this particular one, and not to all others? And seeing that, as we shall find, it has long been endeavoured, now-a-days more than ever, to make engines as light as possible, relatively to their power, how could those of M. *Larmanjat* have in this respect any advantage whatever?

Their characteristic *property*, which the ordinary system will not grudge them for, is a considerable increase of the resistance proper to rolling!

We shall return to the work effected by these engines however, when treating of working inclines, which was the principal object of their inventor.

This system has found powerful enough support in Portugal to get it *tried;* to make it succeed, that is another affair. According to the particulars furnished by M. *Larmanjat* to the *Société des Ingénieurs Civils* (*Paris*), at the commencement of 1870, the first section of the line which was to join *Lisbon* to *Torres Vedras* had then been opened to the extent of 4 miles.

222. *Analogous systems.* — It is not without use to notice that the prin-

ciple was as far back as 1840, tried in perhaps a less objectionable form. A small locomotive constructed by the *Neath Abbey* works in England, carried behind it a big horizontal drum between the rails, which could be lowered, and support a more or less considerable portion of the weight of the engine, by rolling on the ballast.

Like many other ideas taken as new, because they are old and forgotten, this latter one has been disinterred by M. *Cottrau*, inventor of a sort of variation of the *Larmanjat* system; the driving-wheels run between the rails, simple carriers, on an appropriate road surface : bitumen or longitudinal timbers, etc., for the author's ideas seem to be but little defined as to this point.

In a report on these two systems (*) an Italian engineer, already quoted, M. *Biglia*, estimates the increase in the adhesion by such means, at 50 per cent, and that a coefficient of $\frac{1}{4}$ would be always insured.

This is very doubtful, but what however is not so, is the very considerable increase of the engine's rolling friction. The maintenance of the surface exposed to the action of the driving-wheels, or driving-roller would be besides, very costly. If, by chance, the creators of railways had been, at the outset, so badly inspired as to have had recourse to similar expedients, it would not have been long before they put the driving-wheels on the rails, and that would have been most properly looked upon as a very great progress.

Such retrograde inventions are not wanting, especially in the matter of railways.

Believing doubtless that he is saying a great deal, M. *Cottrau* asserts that his engine can draw, on a level, twenty times its weight. There is certainly nothing unreasonable in that. Who does not know that an ordinary locomotive can draw much more, and that without reducing its velocity, far within the limit of adhesion on the rails?

In France, the council-general of the "Ponts et Chaussées", and in Italy the upper-council of the "Genio Civile", have come to the limited conclusion, that from the point of view of simple possibility and safety, the systems *Larmanjat* and *Cottrau* give rise to no objections, but that nothing warrants the economical advantages alleged by their authors. Bodies subjected to great reserve, and who had not besides the complete technical discussion

(*) *Sistemi ferroviari Cottrau et Larmanjat*, p. 5, Florence, 1870.

of the question to deal with, could scarcely pronounce a more marked opinion.

223. Many of the systems are inspired by a desire to do something new, with little trouble, by simply borrowing right and left, or even by leaving something out.

Under the name of *uno-rail* type, an arrangement has been proposed which is nothing else than the central rail system (which we shall study farther on), without the two side rails. In this case, at least, the benefit as regards adhesion is real.

The natural complement would be the reduction of the resistance by the addition of bearing rails; but this would come to the central rail system as applied by M. *Fell*; and this is no doubt the reason why the side rails disappeared in the inventor's project.

§. V. — Adhesion of road engines.

224. *Road engines.* — *Larmanjat's* system, strange combination of railway and road engine, leads us to say a word on *Bray's*, although its study does not come within our scope. Thus, we shall occupy ourselves only with its adhesion, and the endeavours made to increase it.

In England, it is often taken at 600 lbs per ton of load or $\frac{1}{3,73}$; but it is very variable, according to the nature of the road, the state in which the road is kept, and atmospheric conditions. According to M. *Tresca* (*), 0,3 can be taken for the adhesion on a metalled road, "dry and in very good order". But what becomes of this figure, when water is present and with more or less clay in the metalling? Experiments are wanting, but engine builders are all agreed that projections on the tyres are indispensable in that case.

In a trial made at *Montretout*, on an incline of one in 12, paved with stones (*) (the same article says, page 407, on one in 8, but the first figure is right) the adhesion failed with an engine of 8 tons, adherent weight 6 tons, 40, drawing a load of 3 tons, 40. The resistance to traction being 0,04, the necessary adhesion was :

$$f = \frac{(8,00 + 3,40)(0,08 + 0,04)}{6,40} = 0,21.$$

(*) *Annales du Conservatoire*, vol. VIII, 1860, page 299.
(**) do. vol. VII, p. 388.

Moreover, the adherence is in general so little looked on as sufficient, that all the endeavours are directed to the means of increasing it without cutting up the roads. M. *Cail* gives the tyres of the driving-wheels the shape of a pulley groove, into which he drives blocks of wood on end, set up by screws. He thus substitutes the friction of wood on end to that of iron.

Others, as Mr *Aveling* does, are satisfied with covering the surface of the iron tyre of the wheel with asperities, necessarily projecting but slightly.

In *Bray's* engines, it has been sought to carry out between the wheel and the ground, by means of a mechanism somewhat analogous to M. *Cavé's* wheel with movable floats, only the teeth project the more, the less the resistance of the ground. The tyre contains rectangular openings, through which penetrate blocks of iron, fastened by rigid rods jointed on to the collar, turning with the wheel, of a fixed excentric, but of which the position can be varied at will, in such a manner as to regulate the projection of the blocks on the tyre, at the instant of their reaching the ground, according to its degree of consistency. This projection is at a maximum for each block when it comes on to the prolongation of the excentricity towards the centre, and a minimum when it takes the position diametrically opposite. With the excentricity vertical and the centre above the axis of the axle, the block is at its maximum projection, when it is at the upper extremity of the diameter of the wheel, and no projection when it is at the lower extremity, that is to say on the ground. It is the reverse if the centre of the excentric is below the centre of the wheel; the block then has its greatest amount of projection, at the instant of its coming on the ground. To the intermediate positions of the excentric, correspond intermediate values of the projection of the blocks at the moment they reach the ground.

225. *Thomson's tyres.* — But the arrangement which seems to be attended with the greatest success, at least in most cases, is that devised by Mr *W. Thomson*, of *Edinburgh*. It consists in the application on to the iron tyre, of a very thick (0 ft, 38) vulcanised india-rubber tyre. This tyre constitutes the sole bearing spring of the engine. As a spring, its position is most favourable, because it receives shocks directly; thus it has been long tried in England, as we shall see farther on, to apply the same principle to locomotive wheels. But the fitting on of this india-rubber tyre requires special precautions. It has to be put on almost without tension, otherwise it rapidly destroys; and at the same time the iron tyre must not slip on it. The whole is reconciled by putting it on slack, and piercing it all over with rounded

out holes, three quarters of an inch in diameter, in the iron tyre. On the portion compressed between the wheel and the ground, the india-rubber penetrates into these openings, and thus establishes a solid connection which is sufficient to prevent all slipping.

The main feature of the india-rubber is a considerable increase of the surface over which the pressure is spread; a most valuable property on a compressible soil; the sinking in of the wheels, and consequently the resistance, being much reduced. It is thus that the engine, with the condition, of course, of broad enough tyres, runs over ploughed fields without making ruts.

As to adhesion, this increase of surface could have, taking all known facts into account, no effect, or if any an injurious one. Experience shows however, that it is not so with india-rubber.

It may easily be conceived that the influence of the extent of surface may change in effect from one body to another. If, in effect, the number of asperities which take one into the other, increases with this extent, on the other hand, the depth with which they mutually catch hold ought to decrease at the same time; in such a way that if, in this sort of toothed gearing, the number of teeth in gear increases with the surface, the resistance of each tooth, as they take less hold, may very readily diminish; and there is then nothing surprising that one or the other of these elements should predominate according to the nature of the substances.

The india-rubber is however not uncovered. It was so first, but its rapid wear on most surfaces soon proved the necessity of protecting it. The adhesion failed besides on metalling, renowed with clayey lime-stone, forming in time of rain, an unctuous and slippery mud. But the question was above all to save the india-rubber. The covering adopted by Mr *Thomson*, is composed of series of narrow steel-plates joined by side links, and forming a chain without tension, and independent of the tyre, as the tyre is independent of the iron rim of the wheel, the projecting sides of which keep the chain in place.

These plates do not touch; they are 5 inches broad, and 1 in,5 apart from edge to edge. The surface of the tyre is thus compound: nearly $\frac{3}{4}$ metal, and india rubber for the rest. Under these conditions the benefit of adhesion is necessarily much reduced, to nothing indeed on some roads, according to some English engineers. There would thus remain only the elasticity of the tyres; an incontestable value, besides; but which should not be paid for too dearly. At the price of india-rubber, it does not appear that it could in any case ever be used uncovered; and the circumstances in

which it is suitable to be used with the metallic covering have not yet been studied or noted.

M. *Grenier*, of Grenoble, constructed for the iron-works of *Allevard*, a road locomotive with *Thomson's* tyres, intended to carry the materials for the works up one in 11.

The load on the driving wheels is 10 tons. A dynamometric experiment, made in the yard of the workshops, at *Grenoble*, gave for effort of traction of the engine fastened to a fixed point, 5 tons, whence it has been concluded that the adhesion is as much as $\frac{1}{2}$. This is incorrect. The effort thus measured, is not only the adhesion but the resistance to rolling. Admitting that all that was marked by the dynamometer was adhesion, friction, we should come to this conclusion at the limit: that the effort necessary to extricate a vehicle stuck in the mud, has nothing but adhesion to overcome. Doubtless, the ground on which the experiment was made was firm and solid; but it is not the less true that the resistance measured, included other elements than adhesion; and that the method of estimating it made use of, although quite right on a railway, is more or less involved in inaccuracy on stone metalling. The figure of 5 tons marked by the dynamometer, for a load of 10 tons, is thus in reality much less favourable than it appears at first sight. It may quite as much prove, if not more so, the amount of the rolling resistance of the engine, weighing 16 tons in all, as the real amount of the adhesion. On the other hand, the effort of 5 tons, whatever may be its real signification is an extreme limit; in thus pushing the trial to the utmost, one of the tyres was damaged, the india-rubber of which became disaggregated where it rested on the ground, with a liquid exudation. As the pair of tyres costs £ 200 (at 3 shil. 6 d. a pound) the greatest care has to be taken with such expensive appurtenances.

Although in making turns, the inside wheel can be locked, the other only working, the tyre of the inside one necessarily suffers a great deal in pivotting round being so broad.

Whatever may be the uncertainty which still reigns as to the industrial value of this application of india-rubber, particularly as regards the increase of adherence, M. *Larmanjat* naturally did not fail to see in it a new chance of success, and a new argument in favour of his system. It does not appear however, that any trials have been made hitherto in that direction.

226. Special constructors, *Aveling* and *Greig*, have endeavoured to

render the application of india-rubber less expensive, by replacing the tyre all in one piece, by a series of segments placed side by side, and kept in place by iron stirrups let into the iron rim. Any particular damage is thus confined to one segment, which may be replaced.

Of course endeavours have been made to obtain the same effects as with india-rubber, by means of less costly substances. *Nairn's* elastic tyre is formed of series of cords 1,2 inches in diameter nearly, in seven layers one over the other, and kept in their places by iron stirrups. At the end of a certain time all the ropes form a compact mass. An engine of 7 tons adherent weight, furnished with these tyres, drew, it is stated, 18 tons up one in 12, which would give for the effect of gravity alone, an amount of adhesion utilised of $\frac{1}{3,3}$. This is possible, but the sort of ground and the atmospheric circumstances should have been given.

227. Without prolonging this digression, let us bear in mind that the road locomotive, has not been able to enter practically as a means of carriage.

Traction by horses is generally much cheaper, and the cases where forage being dear and coal cheap, would lean the balance over in favour of the road engines, are up to the present time very rare. The failure of the attempt made by the *Geneva* company of the colony of *Setif* : a service of road engines, established in 1868 between that town and the sea, was put a stop to as soon as 1869, that short experiment having abundantly proved the superiority of ordinary carriage.

Save with very rare exceptions, the locomotive is only in its place on a railway or tramway, and on a solidly established permanent way, well maintained, and of course very costly. The requirements of a railway for horse traction are far less; thus that solution seems susceptible of much less restricted application than locomotive traction on metalled or paved roads.

228. — *Sledge locomotive.* — There is one quite special case to which the road engine can be applied, that of drawing on ice. The smallness of the coefficient of friction allows all the carrying wheels to be dispensed with, in the engine, as in the vehicles. The front directing train jointed vertically as ordinarily is a simple sledge, and the adhesion of the driving wheels, the only wheels in the whole thing, is amply got by roughing them. *Neilson* of *Glasgow*, has constructed such an engine, which has been made use of on the *Neva* at *St. Petersburgh.*

CHAPTER III.

FEATURES OF THE DIFFERENT TYPES OF LOCOMOTIVES.

We now come to the study of the locomotive, considered as a vehicle, one of the axles of which receives a movement of rotation.

This axle is driven by two pistons, acting on two cranks at right angles;

These cranks and these cylinders, may be placed either within the wheels or outside;

The frame may be, similarly, either inside with reference to the wheels, outside, composite, or double, both inside and outside together;

The mechanism of distribution, may, similarly, be placed either within the wheels, or outside;

The number of axles varies from the minimum of two, to four, five, and even six;

The position of the axle driven directly by the pistons may vary;

There may be grounds for making two, three, or more axles, driving axles.

Let us examine these different points.

§ I.— Double driving machinery.

229. The motives for this division of the moving power are so evident, that it is almost unnecessary to point them out.

With one single cylinder, the starting of the engine, in case of its stopping at the dead points, could only be done by the pinchbar, inserted between the wheels, and the rail. The cylinder having its axis necessarily in the plane of symmetry of the engine, the boiler would have to be raised for too high, so that the big end of the connecting rod could clear the bottom thereof.

On a railway, the vehicles, waggons or engines are not exposed to turning over. The consideration of the height of the centre of gravity, so important on common roads, only comes in, in this case, at a certain point. English engineers, especially, pay very little attention to it, too little perhaps. This height has no direct influence on the stability but if too much,

it has an indirect one, for it increases the amplitude of the oscillations, particularly the cross ones, which the engine tends to perform under the action of several causes which we shall analyse. It affects also, the conditions of running through curves. If the English hold this matter of height so lightly, it is because they generally make a point of combining in their engines, the essential conditions of stability, that is to say: inside cylinders, long wheel-base, wide elastic base.

With two cylinders, by placing them outside the wheels, the double-cranked axle, a costly and complicated piece, can be got rid of, which is the more to be desired, as these axles run a much shorter distance than straight ones; they always finish by breaking, and never by wearing down of the journals.

When in motion, one single cylinder would be sufficient, the train then forming a reservoir of *vis viva* considerable enough to compensate for the variations of the moving-power, without the velocity being sensibly affected. A single engine has, in fact, been applied under analogous conditions, that is to say to steamboats; in France to river boats, in the *United States* to transatlantic packets, such as the *Ariel*, the *Vanderbilt*, which navigated between *Havre* and *New-York* before the war of secession, etc. But the conditions of service are very different; the stoppages of steamboats are much less frequent, none at all indeed at sea; the driving shaft does not fulfil as in the locomotive, the function of an axle, and an axle heavily loaded, so that the body of the shaft, driven by the middle, has only to undergo, the effort of torsion, received from the connecting rod.

In its infancy, however, the locomotive also, had only one cylinder. The first one of all, that of *Trewithick* and *Vivian*, constructed in 1802, had only one cylinder, horizontal; the cranked axle driven by the connecting rod, transmitted by means of gearing, the movement to the axle of the driving wheels, provided with a fly-wheel which served at the same time as crane-brake. The second engine made by the same, in 1804, and *Blackett's*, had only one cylinder, vertical and fixed inside the boiler. It was *George Stephenson* who, in 1814, adopted the double machinery, and thus conferred on the locomotive one of its essential features, which it retains still to-day, but under a very different form; the two cylinders of *George Stephenson's* engine were vertical, and each of them drove one of the axles; the total adhesion was thus utilised without coupling; the position of the two cranks was maintained at right angles by a contrivance which has recently reappeared, in the engines constructed by the firm of *Cail* and *Co*, for *Fell's* railway over Mont Cenis, and which will be described farther on.

With two cranks at right angle,. starting is insured in all the positions of the driving axle; but under one condition, that is that the period of admission of the steam be long enough; if for example, it did not exceed one half the stroke, direct starting would be impossible, were one of the pistons at the extremity of its stroke, that is to say at the dead-point, and the other of course at half stroke; a position in which, under the supposition in question, the steam would not enter on the latter. This is, in fact, one of the motives which render a great degree of fixed expansion impossible in locomotives. In the position assumed, the steam must have a considerable opening to enter on the only one of the pistons which is then able to act.

As just explained, an approximate uniformity of movement of translation, would take place even with a simple piston, with constant pressure and the same gradient, thanks to the considerable mass of the train, very slight variations in velocity, corresponding to great variations of *vis viva*. This uniformity of movement of translation takes place *a fortiori* with two pistons, and it involves that of the rotation of the driving wheels, which would not take periodic movement, without the occurrence of sliding, or slight slipping, which are not produced, at least in general.

The application of a countor to the driving axle, seems in fact, never to have brought out any notable discrepances between the distances measured on the rails, and at the circumference of the driving wheels. The varied periodic movement of the driving axle, coinciding with a uniform movement of translation of the whole mass, is on the contrary, very perceptible in paddle wheel steamers whenever they are running slowly.

230. *Expression of the couple of rotation.* — In locomotives, as in many fixed engines, it is then precisely the uniformity of the rotation of the driying axle, the result of the uniformity of the translation of the entire mass, which determines the law according to which the work is given out.

The value, continually variable of the couple of rotation, is easily obtained :

1. *Right side.* — (π, mean effective pressure on the piston; r, the radius of the crank; b length of the connecting-rod; α, β, the simultaneous angles made by the crank and connecting rod respectively, with the horizon). — (Pl. XX, *fig.* 12). The couple is :

$$M = \frac{\pi r}{\cos \beta} \sin (180^\circ - \alpha + \beta)$$

$$= \pi r (\sin \alpha - \text{tang}\,\beta \cos \alpha) = \pi r \sin \alpha \left(1 - \frac{r\sqrt{1-\sin^2 \alpha}}{\sqrt{b^2 - r^2 \sin^2 \alpha}}\right).$$

Each of the two factors, and consequently the moment itself, is a maximum for $\sin\alpha = 1$, which gives $M = \pi r$.

Sin α changes sign, passing through o, for $\alpha = 180^\circ$. But as π changes sign at the same time, the direction of the couple remains the same.

2. *Left side.* — The right hand crank being horizontal, and behind the axis of the axle, the left hand crank, vertical, might be either above or below that axis. It is this second position which is always given to it; so that, when the right hand piston is at the zero point of the forward stroke, the left hand piston is at the middle of the return stroke.

The left hand moment, passes through the same values as the right hand one, for a whole revolution; but when the right hand crank makes the angle α with the horizon, the left hand one makes therewith an angle of $270^\circ + \alpha$; in order to get the simultaneous value of the second moment, we must replace α in the expression of the first by $270^\circ + \alpha$: which gives, π' being the mean effective pressure on that side :

$$M' = -\pi' r \cos\alpha \left(1 - \frac{r\sqrt{1-\cos^2\alpha}}{\sqrt{b^2 - r^2\cos^2\alpha}}\right)$$

maximum value for $\cos\alpha = -1$, which gives $M' = \pi' r$.

Cos α changes sign for $\alpha > 90^\circ$, but as π' changes direction at the same time, the direction of the couple is always the same. In fine, π and π' have sometimes the same sign, sometimes contrary signs, but the correlative signs of $\sin\alpha$ and $\cos\alpha$, are such that $\pi \sin\alpha$, and $-\pi'\cos\alpha$ are always in the same direction :

Right.	*Left.*
1st Quadrant ($\alpha=0$ to $\alpha=90$) : π pos., $\sin\alpha$ pos., $\pi\sin\alpha +$.	π' neg., $\cos\alpha$ pos., $-\pi'\cos\alpha +$.
2nd Quadrant ($\alpha=90$ to $\alpha=180$) : π pos., $\sin\alpha$ pos., $\pi\sin\alpha +$.	π' pos., $\cos\alpha$ neg., $-\pi'\cos\alpha +$.
3rd Quadrant ($\alpha=180$ to $\alpha=270$) : π neg., $\sin\alpha$ neg., $\pi\sin\alpha +$.	π' pos., $\cos\alpha$ neg., $-\pi'\cos\alpha +$.
4th Quadrant ($\alpha=270$ to $\alpha=360$) : π neg., $\sin\alpha$ neg., $\pi\sin\alpha +$.	π' neg., $\cos\alpha$ pos., $-\pi'\cos\alpha +$.

The value of the resulting couple is given for every quadrant by adding M and M′, giving π and π' their correlative signs, and the same absolute value.

231. *Locomotives with three cylinders.* — It has been proposed to apply three pistons to the driving axle. *Robert Stephenson* even constructed engines of

this type for the express trains between *York* and *Newcastle* (Pl. LXXXVIII, *fig.* 4). But the two extreme cylinders, outside, had their cranks parallel, in the same direction, and at 90° with that of the intermediate cylinder, an arrangement which evidently was not the best calculated to regulate the movement of rotation : his intention was, in effect, not to bring the moving couple nearer uniformity, but to destroy, one, and the most serious of the disturbances due to the non symmetry of the two lateral systems of pieces animated by relative movements: swinging.

	DIAMETER.	STROKE.
	feet.	feet.
Outside cylinder.	0,88	1,84
Inside cylinder	1,36	1,50

The volume $d^2 l$, and consequently the effort of traction, were therefore the same for the centre cylinder, and for the two others together.

But the result did not justify the complication. Mr *Haswell*, has however carried it still farther, by taking four cylinders, as we shall see hereafter, always with the view of the same advantage, obtained it is true, more completely: the destruction of the disturbances; but the end is attained much more simply by counterbalance weights. (278 and follow.)

Robert Stephenson's three cylinders engines have, besides, been given up years ago.

§ II. — **Position of the cylinders relatively to the wheels.**

232. Inside cylinders have the drawback of requiring a cranked-axle, and the advantage of reducing the width of the engine, of rendering its running steadier, giving more room for placing the leading axle, and leaving the outside face of the wheels, free, either for outside longitudinal beams, or coupling rods. Thus inside-cylinder engines have long been preferred for low speed, and consequently coupled engines. But now-a-days outside cylinders generally prevail, even for coupled engines, unless in England.

In very powerful engines, the large diameter of the cylinders may be a further motive for placing them outside, even if the frame be inside. There is not, in fact, between these longitudinals, only about 4 feet apart, room enough to lodge two cylinders more than 1 ft, 41, to 1 ft, 44 in diameter, with an intermediate steam chest, taking the two vertical slides, even made as

narrow as possible. On this account the valves have sometimes been placed under the cylinders, a very inconvenient arrangement particularly for looking after them; this has even been adopted, without any grounds as regards to size of cylinders or want of room, in one of the types of goods engines on the Western of France, for example Pl. XLII, *fig.* 3. The objection founded on want of room, disappears moreover, if the valve boxes are brought outside the cylinders and frame plates, which places the machinery of distribution outside, a point generally aimed at in the present day, and rightly, on its own account, whatever otherwise may be the position of the cylinders relatively to the wheels.

Inside cylinders require, but less than one single cylinder (229), the boiler to be raised up above the axles, which leads to the centre of gravity of high speed engines of course with large wheels, being brought very high up above the rails. This is particularly marked with inside frames, and in engines of great power; the axle-cranks being nearer together the greater the diameter of the cylinders, and longer the greater the stroke, and having to come under the lowest part of the boiler.

However it is not only for goods engines, but also for high speed engines that English engineers, in accord with the Belgian State engineers in this, and now-a-days with those of the Northern of France, persist in placing their cylinders inside. They insist on this point, that bringing the cylinders near to the plane of symmetry of the engine is very favourable to regularity and steadiness of running at high speeds. It is certainly not without advantage to reduce the distance between the centres of the cylinders, that is to say the leverage of the couple which produces the swinging motion; this distance, which may be reduced to 1 ft,6 in inside cylinder engines, is as much as four times greater, and even more, in certain outside cylinders engines; but that is in the case of slow speed engines, which, by that very fact it is true, that is to say by the smallness of their wheels, are badly adapted to the application of the ordinary remedy : counterbalance weights. The example of the engines of other countries, France particularly, proves fairly enough that the position of the cylinders outside, does not prevent, even at high speed, an amount of stability very sufficient for safety, if it does not permit such smooth running as in English engines. More attention is given in France than in England to avoiding the draw-backs of cranked axles.

Preference given in France to outside cylinders. Example : At the 1st of january 1872 *Paris and Méditerranée* lines had altogether 1.601 locomotives, of which 1.097 had outside cylinders, and 504 inside cylinders.

According to the different sorts of trains these engines work, the above figures are thus distributed:

	OUTSIDE cylinders.	INSIDE cylinders.
Express (uncoupled, and four wheels coupled)	78	26
Ordinary (do do)	321	118
Tank-engines (four wheels coupled)	0	4
Engerth engines (four wheels coupled)	0	32
Goods (six wheels coupled)	653	222
do do *Engerth's*	7	0
do (eight wheels coupled)	24	0
Shunting engines (six wheels coupled)	11	102
	1.097	504

The ratio will go on increasing, from day to day in favour of outside cylinders. Since 1860, no inside cylinder engine has been ordered, excepting for shunting engines, for which inside cylinders are preferred on account of their less width.

§ III. — Position of the frame.

233. The frame, which is the general support of the boiler and machinery, consists essentially of two and sometimes of several longitudinals fastened together by cross beams, extreme and intermediate.

It conveys the load on to the journals of the axles, by the intermedium of the bearing springs: the axles being solidly maintained with the frame by guard plates, similar to those of waggons, which take on to the sides of the axle boxes by broad sliding pieces put on to them, and often furnished with wedges with setting up screws to prevent *knocking*. (V, V, Pl. XXV, *fig.* 1; and Pl. XIX, XXXIX, L, LVI.)

It is by its thrust on these plates that the driving axle takes on the frame, which in its turn, as in waggons, takes on the carrying axles by their guard-plates.

The motives (8) which lead the frame to be placed outside the wheels, in carrying-stock, on outside journals, apply also to engines, in as much as they are vehicles. But these motives have often to yield to others, special to the engine. In the latter, the frame is not placed above the wheels, as in waggons, unless in quite particular instances; the boiler, being between the wheels, cannot rest on outside frames excepting by means of brackets,

unless the wheels are very small; which is very much less rect and less simple, than with inside longitudinals applied directly against the fire and smoke boxes. Whe shall return to this placing of the boiler, after having studied it itself. On the other hand, the position of the frame is bound by that of the cylinders, to a certain extent. The most perfect and immovable solidity of connection between the cylinders and the frame is one of the most imperative conditions in the construction of locomotives. Objection was taken, nct without reason, to *Sharp Roberts's* engines, with inside cylinders and outside frames, in which the connection between the cylinders and the frame is effected through the boiler, which is thereby subjected to strains from which it should be withheld. This is what *Stephenson* did in a type which has remained famous (*new patent*), with inside cylinders and inside frames. The cylinders and their joint steam chest, cast in two pieces solidly bolted together, have two lateral appurtenances, with shoulders by which the whole rèsts on the edges of the two longitudinals, to which they are fastened by bolts, only in tension. This method has become almost classic. It applies equally, of course, to outside cylinders, on the sole condition of a special and very solid connection, on account of the much greater distance between them; but inside longitudinals also suit better for inside cylinders, without, however, their being incompatible. Thus, this arrangement is found in the coupled high speed engines of the Western of France (Pl. XXXIII and XXXIV). The cylinders each cast as usual in one piece, with its valve box, are fastened together by means of flanges forming a joint bolted in the centre of the engine: they thus form a perfectly solid whole, which rests by shoulders on the edge of each of the longitudinal plates l', l'. The same arrangement characterises also, the engines built by *Polonceau* for the *Orleans* lines. It has, as well, some advantages with reference to the lowering of the boiler, and the solidity of the cranked-axle, because it conduces to bringing the cylinders and consequently the cranks close to the wheels, which are let into, and indeed form part of the nave.

If cylinders and frame are both outside, the connecting rod ought to work on to a crank brought on to the journal produced. The width of the engine is increased, and the journal then undergoing the strain of the connecting-rod, its diameter ought to be calculated in consequence, and not merely with reference to the load.

One of the advantages presented by the outside position of the journals, as regards the carrying axles, that is to say the relative smallness of their diameter, disappears then to a great extent, for the driving axle, and for those coupled thereto.

It would be better, then, in this respect, to place the longitudinals on the other side of the wheels, when the cylinders are outside. This is what is generally done, except in Germany and Austria, where outside cylinders and outside frames are very frequent, even in engines having all their wheels coupled; whence results a new cause of widening the engine, and an increase of the couple (necessarily destroyed besides by the connections of the system) which tends to cause each of the wheels, solidly connected together by the coupling rods, to turn round on the vertical passing through its point of support on the rail.

This arrangement affects, besides, the width of the space between the lines, and the clear way left by the works, such as bridges and so on. It is thus that the most of the German engines, are too wide for our templates.

234. *Hall's crank-journal.* — The inconvenience of excessive width of the engine can be reduced by taking as journal the shank M of the crank B (Pl. XVIII, *figs.* 13 and 14). The diameter of the journal of course is increased; but a considerable gain in width is got. The arm of the crank takes up very little room, the conditions indeed, under which it works conducing to increase it in a direction parallel to the rod, and of course reduce it cross-ways.

This constructive detail is widely adopted in Germany, where the circumstances that warrant its application, are frequently met with, that is to say the co-existence of outside cylinders, outside frames and coupling of the front wheels. It is known there as *Hall's* system, although the priority of the idea would seem to belong to M. *Meyer* of *Mulhouse*. It will be noticed on plates XIX and XX; XXIV; XXV to XXVII; LIII and LIV, where the cranks are marked with the letter *m*.

Inside frames predominate now-a-days, unless in Germany. They also have their drawbacks: still thicker journals, a narrower elastic base, as well as, often, a serious difficulty in placing the bearing springs in the space ordinarily so contracted, comprised between the boiler and the inside faces of the wheels. For the longitudinal beam, the matter is disposed of by forming them of a plate of iron on edge; while placed outside they can be thicker, and even if desired, of wood strengthened with iron, an arrangement greatly used formerly, but almost entirely given up at present.

As to the bearing-springs, the breadth of the plates of which they are formed, necessarily greater than the thickness of the internal longitudinal beam, does not always allow of their being placed directly above it. Thus when the boiler should be of great power, and consequently have a large dia-

meter, it is necessary to have recourse to divers expedients for hanging inside frames; we shall point out these when we come to suspension.

235. *Limit of the diameter of the boiler. Influence of the diameter of the wheels.* — The diameter of the boiler is not, of course, always limited by the distance between the wheels, that is to say by the gauge of the line. That depends on the diameter of the wheels; if they are large, the boiler ought of course to be put between them, with sufficient play to prevent any contact in the transversal oscillations imparted by the bearing-springs. If the wheels are small, the boiler can be placed above them without exaggerating its height above the rails. Its diameter is not then controlled by the distance between the wheels (about 4 ft, 46), and is only so by considerations appertaining to the boiler itself, particularly by the relation which exists between the diameter and the thickness of the plates, at equal pressure; for this thickness cannot be carried beyond a certain very restricted limit, without deterioration of the quality of the metal.

It is easy to understand then, why the diameter of the boiler does not exceed 4 feet, in engines with large wheels, that is to say for passenger trains; while in engines with small wheels, or goods engines, it reaches 3 ft, 92 and even 5 ft, 25, in one of the types of the *Orleans* lines (ten wheeled engine, Pl. LVIII to LX).

This independence of the diameter of the boiler, and the gauge of the line, is obtained without bringing up the height of the boiler above the rails, as high as is required in engines with large wheels, solely to get the driving axle under it.

236. *Relative safety of inside and outside frames.* — The two frames have been often compared together with regard to safety, that is to say, the possible consequences of broken axles. These breakages ordinarily take place (unless with cranked axles, when they most often affect the cranks), close to the internal face of the nave. If the frame is outside, the wheel under the action of the load, goes over against, and rests thereon. The wheel may leave the rail, but kept up by the longitudinal, it does not fall, and still supports the engine. With the frame inside, the wheel completely detached, and no longer kept up, is much more likely to fall, and whether it fall or not, it cannot support any thing. It would not be so if the breakage took place beyond the inside journal; the wheel would then go over to the inside, would rest against the boiler, and would not leave the rail; but this observation, sometimes brought up as an argument in favour of the

inside frame, is without effect, as the fracture of an axle very rarely takes place in that way.

" It was long thought" says M. *Perdonnet* (*) " that on the occasion of the accident of the 8th May (*Versailles*, left bank) the front wheel or at least one of the front wheels of the engine, *which had an outside frame* having turned over in consequence of the fracture of the axle, the engine was thrown over. A more attentive study of the facts showed that the engine was not in reality thrown over. It had only gone off the line, and very probably its doing so was not caused by, but the cause of the breakage of the axle. "

I am not aware on what grounds this last opinion is founded: but a certain superiority as regards safety can scarcely be refused to outside frames, which have the treble advantage besides, of a broader elastic base, a greater latitude in the diameter of the boiler, and an easier means of fitting on the bearing springs. This was also the opinion of Mr *Bury*. As Mr *Clark* (**), he gives no opinion, and confines himself to remarking that often, in the discussions of questions of safety, arguments are easily found on both sides.

237. *Double frame.* — Nothing hinders the two methods being employed : to apply an outside frame to the carrying wheels, that is to say placed in the same conditions as those of carrying stock, and to load the driving axle or axles inside : hence the double frame. Introduced into France by Mr *Buddicom*, on to the Western line, it has since been frequently applied, to the *Crampton* engines amongst others (249).

The double frame is pretty often employed in a somewhat different form. The inside frame does not always load only the driving wheel, but the outside frame loads all the axles, the driving one, among the others. This complication can only be warranted with inside cylinder engine, because it diminishes the strain on the cranked axle. There would be no use for it with straight axles.

It has been applied, for example : 1, to the new high speed engines of the *Northern of France* (Pl. XXX to XXXII) ; the load applied to the driving axle by the inside longitudinal beam is relatively very slight, the spring ρ which transmits it being arranged on purpose to carry 1 tn,80 out of 7 tons, the normal statical load of the driving axle, according to M. *Beugniot*; 2, by Mr *Armstrong* to the new type of inside cylinder goods engines of the Great Western narrow gauge lines (4 ft,72). The six wheels being coupled, the

(*) *Traité élémentaire des chemins de fer*, vol. III, p. 86.

(**) *Railway machinery*, page 13.

outside frame required cranks to be keyed on to the ends of the axles; this is the drawback already pointed out (233) to the combination of the outside frame with coupled wheels; 3, by Mr *Craven* to the engines constructed in the *Brighton* works, for the heavy goods traffic of the *London*, *Brighton* and *South-coast*, etc.

The double frame has the advantage of offering a very convenient means of fixing for outside cylinders, which are solidly bolted on to the two longitudinals at once. As shown by plate XXII, *fig.* 2 (*Great Eastern* engine constructed at the *Creusot* works), each cylinder rests by shouldered flanges cast on, on the sides of the longitudinals l, l', to which these flanges are bolted.

As inside cylinders are fastened only to the inside longitudinals, these other frames do not contribute to the solidity of their position. But the two cylinders, so connected solidly together, as to form (233) one single piece, are very conveniently installed between the inside longitudinals. (Pl. XXXII, *fig.* 2, express engine of the Northern of France).

Engines with inside cylinders pretty often have a middle longitudinal, between the fire and smoke boxes, and which brings a slight portion of the load on to the middle axle, by means of a spring above or below; the coupled engine of the Western of France, built by M. *Gouin*, offers an example of this, combined with a particular arrangement of the driving-wheel, to which we shall return farther on. The principal longitudinals l', l' (Pl. XXXIII and XXXIV), are outside and bring load upon all the wheels. A partial central longitudinal l, l (Pl. XXXIV, *fig.* 1) loads the driving axle in the middle, by means of the spindles c, c, and of the lower spring ρ. Sometimes also this intermediate longitudinal does not load the cranked axle, and the bearings by which it takes hold of that axle have no other object than to keep its centre fixed horizontally, and so to reduce its deflection.

238. *Leading axles with double journals.* — The application of the load on both sides of the wheels, introduced in inside cylinder engines to save the cranked-axle, is somewhat extensive in England, as regards the leading axle of high speed engines with outside frames. But this distribution of the weight between the two sides of the wheels, is effected in that case without any addition of inside longitudinals, even partially. The two inside journals F, F, are loaded by one cross spring T, T, taking the load directly from the boiler (Pl. XXII and XXIII).

The principal aim of the double journals is therefore a security against the breaking of the leading axle. In reality, the breakage of straight axles in engines is very rare; by the attentive way in which they are watched, cracks get almost always found out if visible, and prevent so total fracture; and,

if it should happen at a hidden part, it rarely produces serious consequences, while the breakage of a waggon axle is often very disastrous.

It is well to remark at once in what this difference consists. The breakage of waggon axles would generally be harmless also, if the driver were immediately aware of them. Their effects : broken hornplates, wheels off and jammed against those of the following vehicles, smashed couplings, running off the line, carriages overturned, etc., are not instantaneous. These effects occur in succession, and become aggravated in a running train, especially at a high speed; the driver only, as too often happens, learns by a signal or by the effects themselves, what has taken place, and of course when it is too late. Nothing of the sort occurs in the case of an engine axle breaking: the driver immediately warned by the irregularity of the engines running, does what is necessary, that is to say he stops, without however doing it too suddenly, which might cause a wheel to come off.

Another argument in favour of double journals is that they diminish the tendency to heating. Although less loaded than the driving axle, the leading axle tends to heat more, on account of the greater velocity at the surface of the journals. The reduction of the load on the unit of surface compensates for this effect of the velocity; the double journal becomes equivalent to one single very long journal.

239. *Partial outside longitudinal beam.* — Often enough, the frame is double only for a portion of its length. Thus the altered engines, with inside cylinders, leading wheels coupled of the *Méditerranée* lines, have a complete inside longitudinal, and, behind, a partial outside one. This arrangement arises from a fact of high importance, to which we shall revert: the position of the hind axle under the fire box, and the desirability if not the necessity, of keeping the axle-boxes at a distance therefrom, so as to be out of the reach of radiation.

The engines in question offer an instructive example; that of a quite old type, the proportions and the distribution of which were defective, which it was difficult to utilise, and the defects of which were remedied at a relatively small expense. The heating surface was too small; the load on the rails, engine full, was 11 tons for each of the two first coupled axles, and 4 tons for the third, placed behind the fire box. The body of the boiler was lengthened by 2 ft, 46, without changing anything either in the machinery or in the position of the axles. The grate was thus brought over the hind axle, the load on which was increased in two ways : the increase in the total weight, and by the centre of gravity being brought nearer. There are thus 10 tns, 9 on each of the coupled axles, and 6 tns, 8 on the third.

The outside longitudinal carried backwards, combined with the position of the third axle under the fire box, is to be found also, among the numerous types of the Northern of France, to which we shall soon return (247), and in the tenwheeled engines of the *Orleans* lines (261).

Compound frames. Examples are found in some engines of a truly compound frame; that is to say that the same longitudinal, inside for one portion of its length, inflects horizontally and then goes outside the wheels. Of this shape are the frames of the engines with eight wheels coupled, made by altering the old *Engerth's* (*Creusot* type) of the Eastern of France, and the engines constructed on that pattern at *Graffenstaden*, some for the Eastern of France, and some for the *Paris-Mediterranée* lines. The inside distance between the longitudinals goes from 4 feet, to 5 ft, 26 (Eastern of France) and from 3 ft, 97 to 5 ft, 36 (*Méditerranée*), to take in the fire box, the width of which is 5 ft, 01 and 5 ft, 02. This difference of distance is compensated for by the bending out of the longitudinals; their section 0 ft, 85 by 0 ft, 01, is carried to 5 ft, 98 by 0 ft, 026, at the bend: an increase of strength necessary on account both of the shape of the piece and the length (9 ft, 41 and 9 ft, 81) of the overhanging portion, for there is no axle loaded directly by these outside longitudinals.

240. *Details of frames.* — Wrought iron plates are alone employed now-a-days for longitudinals; they are cut out of great plates, the drawing out, rolling and working of which require very extensive and powerful appliances; so that the manufacture of these longitudinals, is at present confined to a small number of great workshops.

These large plates for longitudinals, the thickness of which varies from 1 inch to 1 in, 4, and the weight of which exceeds 2 tons, sometimes leave the forge (at *Petin, Gaudet's* for example) so nearly in their definitive form, as to leave but little to be done afterwards.

They are cut out so as to combine resistance, lightness, facility of access to the internal parts; and to offer convenient support to the whole machinery.

I take from M. *Petzholdt* (*) some details of the manufacture at *Seraing*, of the longitudinals of the four wheels coupled engine of the line from *St. Petersburg* to *Tsarkoje*. These longitudinals are cut out of a rectangular slab, 24 ft, 28 × 3 ft, 61, by 1 in, 38 thick, weighing 2 tns, 22, which

(*) *Fabrikation, Prüfung and Übernahme von Eisenbahn-material*, by *A. Petzholdt. Kreidel, Wiesbaden.* 1 vol. in-8oo, 1872.

requires, on account of the waste at 30 per cent, a bloom weighing 2 tns, 88. As such a mass could not be forged at once, it is made into three, each of 0 tn, 97, coming from a pile of 1 tn, 17; the special waste at this first operation being 10 per cent. These three packets are 2 feet wide and 1 ft, 64 thick; two only have a covering piece of No 2 iron, 1 in, 57 thick, the third has none. Each of these piles undergoes the following manipulations: 1st reheat for 2 hours and half in a special furnace, and first hammering which reduces the thickness to 1 ft, 31; 2nd fresh reheat for 2 hours and half which draws out the pile to 2 ft, 30 × 0 ft, 49; 3rd reheat for 1 hour and half, and which brings it down to 3 ft, 61 × 0 ft, 30. These three masses are then put together into one with the two covering pieces outside, and brought to a white heat, which requires several hours. The packet then goes into the rolling mill for thick plates, which brings it at one heat, passing it always in the same direction, down to 1 in, 38 in thickness, and to the corresponding length of 24 ft, 28. Total length of the operation, twelve hours.

M. *Mesmer*, director of the *Graffenstaden* works, has set up a powerful machine there, which allows of piercing and cutting out at one time a packet of longitudinals 0 ft, 66 thick, 33 feet long, and up to 5 ft, 25 broad, a dimension which longitudinals do not attain, but which extends the applications of the machine.

Longitudinals with guard-plates fixed on to their two faces, are generally given up. The guides in which the axle-boxes slide are T shaped, and are reduced almost to angle irons, when the longitudinals are inside; they are then in fact, put as far apart as they can be, and take the axle-boxes near the end, while placed on the outside they can take them near the middle (Pl. XX, XXXI, XXXVI, XLV, *g*, *g*; XLVII, *g*, *g*). These guides are almost always of cast iron, and are strengthened by gussets. The guard-plate is double only when the longitudinal itself is, as in *Sigl's* engines, that is to say when the longitudinal, then necessarily outside, is formed of two thin plates kept apart by cast-iron distance pieces (Pl. XXV and XXVI).

The constant preoccupation of engineers who study the locomotive, to obtain lightness, should lead them to apply steel to the longitudinals, as they do to the boiler (to the barrel at least) and to the parts of the machinery. The large longitudinal beams of the *Orléans* tenwheeled engine, are in *Bessemer* steel; but this appears to be the only application made in France, till now.

Double T iron, a proper section for solids which are really girders, has commenced to be adopted for longitudinals. Those of the fourwheeled engines, constructed at *Graffenstaden* for the *Baden* railways (Pl. XIX and XX,

fig. 1) are 1 ft, 90 deep, and 0 in, 71 thick in the web. Too thin to act as guard plates, this web L is strengthened by a thickening on the outside face of the longitudinal, at the groove which takes the axle-box, while the guide formed in this case of a T iron, is applied on the inside face; these three thicknesses are riveted together; and the lower flange p, p, is removed and replaced by a solid stay. The want of sufficient thickness in the web above the axles, is the sole objection to a section otherwise very rational.

Certain engines, among others those of M. *Krauss's* fourwheeled type, (Pl. XXI) present a peculiarity; the centre part of the frame forms a closed hollow girder, and this capacity B, B, is made use of as a water tank, which allows the engine to run short distances supplying itself. The tank-engines with four coupled wheels, built by *Tywell* of *Lincoln*, offer the same peculiarity.

This is not perhaps an irreproachable combination, rendering as a solid part of the vehicle, in this manner, a space which has to be kept perfectly tight, and therefore requiring frequent repairs, and so putting the whole thing often out of work. Moveable tanks would seem to be preferable, notwithstanding their excess of weight.

§ IV. — **Position of the valve gearing.**

241. Many engine-builders place the various parts of the valve gearing outside the wheels, in order to facilitate their being attended to and oiled during running, and being got at in case of anything going wrong. Importance enough is attached to this point to cause no hesitation in placing the pieces belonging to the valve gearing outside, even when the cylinders and frame plates are inside, and there is nothing outside but the coupling rods. This is the case, if any, to apply *Hall's* crank, which indeed receives thus a double application if, as it is suitable to do under the penalty of making the diameter of the excentric sheaves excessive, they are placed altogether outside. Recourse must then be had to a false crank m, (Pl. XVIII, *fig.* 13) on the pin of which n, are keyed the sheaves, and the crank proper, M N, forms then doubly the journal: by means of the shank M, fixed into the axle, for the bearing of the axle-box; and by the socket N, fastened on to the false crank for the coupling rod, the connecting rod being applied at B. The eightwheeled engine by *Sigl* for Russia (Pl. LIII and LIV) is a remarkable example of this arrangement. The outside machinery does not besides increase the width of the engine, as can be seen.

Fig. 14, Pl. XVIII, represents how things would be with inside gearing, which would dispense with the false crank.

The advantages of the gearing outside must not moreover be exaggerated. The converse position has been adopted by many first rate builders; and it is to be found not only in engines with outside cylinders and frames, and front-wheels coupled (*Graffenstadt* engine, Pl. XIX and XX), but also in *Sigl's* (Pl. XXV to XXVII), and in those of the *Great Eastern* (Pl. XXII and XXIII), which have only outside cylinders and frames without front coupling; in those of the *Méditerranée* (Pl. XXVIII and XXIX), which have only outside cylinders, and in those of the *Northern of France* which have only the side frame outside. On the other hand, the gearing is external in the *Western of France* engines (Pl. XXX and XXXIV), the *Orléans* (Pl. XXV to XXVII), the *Creusot* (Pl. XXVI and XXVII); in all the eightwheeled coupled engines, particularly *Sigl's*; in the tenwheeled coupled engines of the *Orléans* lines (Pl. LVIII to LX); and in those with twelve wheels coupled of the *Northern of France* (Pl. LXI and LXII).

§ VI. — **Number of the axles.**

242. Like all railway vehicles, locomotives have at least two axles. At first this number was kept to; but at the present day it ordinarily is brought to three, often four, and sometimes even to five and six.

This is, of course, the consequence of the work which the engine has to effect, that is to say of its dynamical power.

The total weight is derived from the power, and from this weight combined with the figure admitted for the load per wheel on the rails, results the number of the points of support.

In reality, however advantageous an equal distribution of the weight (which by the way is not always possible) (274) may be in itself, it has often to be departed from, very considerably, in order to insure adhesion. The maximum effort of traction t being given, and the coefficient of adhesion f fixed, the adherent weight ought to be $\frac{t}{f}$ at least. If, as is the case with engines of high speed, drawing of course relatively small loads, this weight does not exceed the load that can fairly be put on one axle, the engine will only have one pair of driving-wheels, and the excess $P - \frac{t}{f}$ will be spread over the other wheels.

If, which is the case with low speed engines, drawing of course loads relatively heavy, the weight $\frac{t}{f}$ is little inferior to P, all the axles must be driven, and it is then proper for the weight to be equally distributed over them, as much as possible.

For engines of mean-speed, and consequently drawing a mean load, $\frac{t}{f}$ is inferior to P, but superior to the maximum load that one pair of wheels can take; two axles then at least must be driven, and spread over them as equally as possible the adherent weight, not only to lower the maximum load, but also, as we shall see (255) for a reason which appertains to the process employed for driving several axles.

If $\frac{t}{f}$ were greater than P, this weight would have to be increased, without which the engine could not utilise its full power under the conditions admitted. This relation only occurs in altogether peculiar circumstances, which we shall define and study in detail later on. It will be sufficient to say here, that beyond those quite special cases, $\frac{t}{f}$ is always inferior to P, *although this weight be always as much as possible reduced*, the work that the engine ought to do being given.

243. *Limit of the statical load.* — The limit of the statical load is not altogether absolute, as may be conceived; the nature of the tyres and of the rails, the diameter of the wheels, the velocity have all to be taken into account. It is generally endeavoured not to exceed 11 to 12 tons per pair of wheels, but without, however, scrupling to go beyond that, if the necessary adherent weight does not exceed that figure too far, which is the case in high speed engines. It follows thence, that it is in these engines that the limit of load per wheel is the highest, which seems scarcely logical, the velocity evidently aggravating the destructive effects of its excess of load. But this disadvantage is often accepted so as only to have a single driving axle, that is to say the engine with the wheels free. There are thus, more particularly in England, passenger engines which have as much as 14 tons on the driving wheels.

That same limit has been admitted and even exceeded, but then with much less disadvantage, in low speed-engines with of course several coupled axles; but what is then desired, is to reduce as much as possible the total number of wheels. Let us mention as example, the *tank-engines* with three axles, two of which are driven, constructed by *Borsig* for the coal-traffic on

the *Silesian* lines. These engines with 1397 sq. feet of heating surface, weigh filled 45 tons, or 15 tons per axle. This load is admissible at a low speed; the weight of 45 tons is, besides, moderate for an engine with 1397 sq. feet of heating surface carrying its coal and water; and we can conceive how a certain exaggeration of the pressure per wheel may be preferred to the addition of a fourth axle increasing the weight, the wheel-base, and the difficulties on curves.

The fourwheeled engines of the *Giovi* incline used to have 16 tons on the driving-axle; but that exaggeration has been given up. In Germany, the *Vereinbarungen* fix (art. 108) 13 tons for the maximum on each wheel; and many lines find that figure too high, while others do not fear to go beyond it, but under certain conditions. Thus Hanover admits 14 tons, but only for new permanent way, and steel-tyres; and Brunswick 15 tons, but only for engines which work steep-gradients, and at very low speed.

244. *Fourwheeled engines.* — As far back as 1829, the program of the celebrated *Liverpool* trial specified six wheels, although the maximum weight of the engine full was fixed at 6 tons only. The reduction of the number of axles to two was only admitted on condition that the weight should not exceed 4 tons and $\frac{1}{2}$; the authors of the program only concerned themselves entirely with the load per wheel, and the weakness of the rails then in use led them to put the limit as low as about one ton.

The six ton engine had to draw on the level 2 tons including its supply van, at the velocity of 10 miles an hour, with an absolute pressure in the boiler of 50 lbs on the square inch, at the most. For an engine of 5 tons the load was to be reduced to 15 tons, and nearly proportionately less for still lighter engines. After the preliminary trials, the conditions were revised, and the load fixed at just three times the weight of the engine full.

Robert Stephenson, whose creation of the *Rocket* on that occasion, was the prelude to the long and glorious series of his works, took advantage of the permission to reduce the number of wheels to four, and succeeded in not exceeding 4 tons and $\frac{1}{4}$, which gave 13 tons and $\frac{3}{4}$ to be drawn. To fulfil the conditions of the program was a trifle for the *Rocket*, with the load of three times its weight, it run 19 and even 24 miles an hour instead of the 10 required; and with a load nearly eight times its weight it reached the velocity of 13 miles an hour.

It is from this time that the locomotive really dates; until then nothing but an imperfect sketch; but the *Rocket* combined at once, what is the secret of the power of the locomotive: the tubular boiler, and the exhaust.

The first locomotive worthy of the name, and those which immediately followed it, had then, only four wheels. This number was afterwards brought to six: the permanent way was however more solidly constructed, so the addition of the third axle was determined by considerations foreign to the limit of the load per wheel.

In fourwheeled engines the length of the base of support was much less than that of the engine, and that disproportion is very detrimental to stability. As long as the speed was low this inconvenience was small; but it went on increasing as the velocity increased. A third axle was then added behind, against the fire-box, which thus ceased to overhang. Loaded but little when the engine was at rest, its principal function was that of improving the stability of the engine, by limiting its oscillations, vertical and horizontal.

Fourwheeled engines had also to disappear in France, on the lines in the environs of *Paris*, in consequence of the terrible accident of the 8th of May 1842. The cause of the disaster, the *Matthew-Murray*, had only four wheels. In prohibiting this type of engine, the Railway Department calmed the fears of the public, whose confidence they restored in virtue of the adage: *Ablatâ causâ tollitur effectus.* It was only however in appearance; the addition of a third axle behind, changed the position of matters but little; with the same combination of circumstances, the breaking of the leading axle would have had the same consequences, if it was the cause, as generally believed, and not simply the effect of running off the line, as M. *Perdonnet* admitted (236). But the interdiction was, after all, the best way of quieting all distrust; and it was attended with less disadvantage, as fourwheeled engine as then constructed, had become generally insufficient for the service of the lines affected by the measure in question, and which was besides only a local and temporary one. In 1857, the *Lyons* Company had full liberty to work its short suburban traffic with the fourwheeled engines which came to it from one of the small lines incorporated in the system; and if these engines were soon given up, it was a free act on the part of the Company, because independently of their defective type, they were far too weak for their work, the only thing to which they could be applied : suburban traffic.

In 1866, the directors of the little line from *Fougères* to *Vitré*, in the fear of coming under the prohibition of 1842, submitted to the Minister of Public Works, that engines with four wheels coupled, carrying their own supplies, and only weighing from 14 to 15 tons, were better suited than any other type to the conditions of gradients and curves, of traffic and speed of that line, and asked for authority for such engines, which was in no way required.

Notwithstanding their being laid aside for several years, fourwheeled

engines are coming a little into favour again now-a-days; a natural consequence of the development, slow enough by the way, of subsidiary lines, with small traffic and light trains. Engine-builders have succeeded in making engines much more powerful than formerly, with the same weight; a result due in part to the more judicious use and better quality of the materials, to better proportions of the heating surface, and, above all, to the far too low pressures of steam given up, which were so long adhered to. Engines can now suffice for a traffic of a certain extent, with only four points of support, and without an excessive load on any wheel. The Exhibition of 1867 offered two remarkable examples with reference to this; the *Graffenstaden* engine (Pls. XIX and XX), and M. *Krauss's* (Pl. XXI). The first with a boiler of cast steel plates, for lightness, weighs empty 23 tons, and full 26 tons, or 13 tons per pair of wheels; the weight compared to the heating surface (981 square feet), is for the engine empty, 51,6 lbs, rather a low figure, to the smallness of which greatly contributed the suppression of a third pair of wheels, always till then applied to engines of the same power. *Krauss's* engine, already referred to (240), some remarkable details of which we shall point out farther on, is, relatively, lighter still; it weighs empty 16 tns, 3, and full with 2tns,42 of water in the tank B, B, of the frame (Pl. XXI, *figs.* 1 and 2), 21tns,8; its weight empty, per square foot of heating surface, is then only 41 lbs.

It is clear that a comparison of weights referred to the unit of heating surface, is only legitimate and significant, when it is a question of boilers having nearly the same mean evaporative power. By making the tubes unduly long, increasing the number of them, and consequently bringing them too close together could be got an engine very light specifically; but this lightness would be a deception, because, without speaking of other drawbacks to which we shall return, the mean efficiency of the heating surface would be considerably reduced. We shall cite farther on as an example, the rule admitted on the *Midi* railway for establishing this comparison between boilers of different proportions.

245. Safety, in all which concerns the consequences of the breakage of the leading axle is in no way compromised by this return to engines with two axles. The addition, pure and simple, of a third axle behind, to the primitive fourwheeled engine, without any other modification, had necessarity the effect of increasing the load on the leading axle. A certain amount of the weight can only be brought on to this axle, by taking from the intermediate axle by the adjustment of the springs (265) a certain fraction of its original load, a fraction which is divided between the two extreme axles in the

inverse ratio of the distances between the axles. Of course, this increase of load on the leading axle can and ought to be allowed for by an increase in section. But if its breakage could involve the breaking down of the engine, before the addition of the third axle, it can do so quite as well after, the position of the centre of gravity of the weight suspended not having changed, and this point being placed in the fourwheeled engine, necessarily in front of the second axle. The additional wheels have no other effect, in the case of the breakage of the leading axle that to tend, and only from a certain point, to limit the rocking motion of the engine, which ought then to lift them.

Moreover, even in the most unfavourable circumstances, that is to say when one of the front wheels being broken, the axle no longer bears any weight, the fall of a fourwheeled engine would not on that account be inevitable, even independently of the action of the couplings. It is sufficient for stability, although precarious it is true, that the centre of gravity G, of the suspended weight should be nearer the hind axle than the front one, for then, it falls within the triangle to which the wheel base is reduced, when one of the points *c* or *d* fails, (Pl. XX, *fig.* 5). Now this condition is necessarily fulfilled in fourwheeled engines with overhanging fire-box. It is in relation with the conditions of adhesion, and consequently of the load on the driving wheel, which is always the hind one; there must, then, be an external cause for the breaking down of the engine if the leading axle breaks. The small engines of the *Lyons* line mentioned just now (244) were in much more unfavourable circumstances in this respect. The driving axle was behind the fire-box, and consequently much farther from the centre of gravity of the suspended weight. In case of the fracture of the leading axle close to the nave of the wheel, such engines, with inside frame, would be almost certain to turn over.

246. *Fourwheeled engines, in Saxony.* — Altogether there are no grounds for rejecting fourwheeled engines, wherever they are sufficient for the work; they are more economical, lighter, they run through stiff curves more easily, even with the same length of base, as well as through sidings and crossings. There is nothing better to be done, than to stick to them, when the weight which corresponds to the necessary dynamical power can be put on only two pairs of wheels, without undue pressure on the rails. They appear to be admissible for any service, but that of high speed. With overhanging fire-box, they would have too short a wheel base, and consequently be unsteady in running. With the driving axle behind the fire-box they would lack adhesion, like *Crampton's* engines (249). High velocity requires

moreover, now-a-days, engines the power of which much exceeds in general, that attainable by fourwheeled engines.

We should add, however, that the experience of the State railways in Saxony, which, for some years,have had since several types of fourwheeled engines in work, seems to be but little favourable to them. These engines weigh 28 tons, have 4 ft, 43 wheels for goods, 4 ft, 92 for mixed or passenger trains, and 5 ft, 41 for express. On lines with sharp curves, at 24 miles an hour only, the running of these latter becomes somewhat unsteady (and it would *a fortiori* be the same for the others), which is explained by the overhanging position of the fire-box, and the relatively too short wheel base.

The load on the wheels undergoes very serious disturbances, as a consequence of course of unsteady running. Thus it was stated for the engines of the 2nd type (for mixed trains) that the load per wheel which is 7 tons when standing, varies during running between 4 and 11 tns, 25. These are certainly excessive discrepancies, but it is doubtful if they should all be put down solely to the system of the engine, and if the state of the line does not count for some portion thereof. A check should have been made on the six-wheeled engines, with the fire-box overhanging also.

But what has also been ascertained is, that the wear of the flanges of the leading wheels is more marked in the fourwheeled engines, than in the six-wheeled ones, in spite of the greater length of wheel base.

This greater wear is perhaps entirely due to the more marked swinging motion of the fourwheeled engine, and the more frequent and more violent shocks resulting therefrom, on straight lines, between the rails and the flanges. It must farther be remarked that if on a curve, the wheel base passes through the rails easier the shorter it is, on the other hand, the couple necessary to impart, at each moment, the change of direction to the engine, requires, with equal mass and length, a greater reaction, the less its leverage, that is to say the length of base.

§ VI. — **Position of the driving axle.**

247. *Motives for not driving the leading axle.* — Wheels driven directly or by coupling ought to support in all a load equal to about seven times the maximum effort of traction. In this respect, in single engines, the driving axle should be that which, according to its position can carry the greatest load.

In engines with four wheels and overhanging fire-box, the hind axle is the most loaded, because it is the nearest to the centre of gravity of the suspended weight, and because it is besides heavier than the leading axle,

if the wheels are free, and consequently of unequal diameters. It would not however be impossible to drive the leading axle. Engines of this sort have worked on the *Liverpool and Manchester* line; the *Rocket* was one (244). Later, in 1838, engines of the same type (*Church's* engine, first application of the tender-engine), ran between *London* and *Birmingham* ; but truly speaking nothing warranted this fancy. The cylinders have to be placed at a considerable distance from the driving axle, so that the connecting-rods may be long enough, and their obliquity moderate. If the leading axle is driving, the cylinders must therefore be brought behind, and consequently also, the centre of gravity of the suspended weight, so that the driving axle is little loaded. Other grounds besides render the leading axle ill suited for a driving axle. On the one hand, as guiding the engine, it undergoes reactions from the rails, to which the other axles are not subjected in the same degree; it is the one the breakage of which may produce the most serious consequences in certain cases. It does not therefore suit to bring on it the increase of strain involved by the special functions of driving axle. Lastly, at equal velocity of rotation, the diameter of driving wheels is proportional to the velocity of translation. Fast engines can no doubt be made with small wheels, by admitting a corresponding increase in the velocity of rotation; but the stroke of the piston must be reduced in the same ratio, under the penalty of subjecting all the parts of the machinery to a rapidly destructive excess of speed. Thence divers drawbacks, especially an unsuitable ratio between the stroke and the diameter of the piston, the increase of the clearance, an excessive number of strokes for the same distance run, etc.

In fact, and without dwelling on this point which we shall take presently (252), the diameter of the driving-wheels of high speed engines often exceeds 6 ft,5, and is seldom below that. A wheel gets the easier over an obstacle of a given height, the greater its diameter; and the flange is nothing else than an obstacle which the wheel has to get over, in order to go off the line. It would be necessary, in order that safety should always be uniform, that the projection of the flange should increase with the diameter. But they do better; to all wheels, large and small, the maximum projection of flange is given which the permanent way allows; and this maximum would cease to give sufficient security for the front wheels, if their diameter exceeded a certain limit, in ratio besides to other elements (type of engine, state of maintenance of the line, speed, etc.). It is from this motive, and also to reduce the weight and the height of the centre of gravity of the engine, that the engineers of the Northern of France, led to drive the two extreme axles in a type of engine intended for high speeds, had reduced the diameter of

the wheels to 5 fts, 25. Experience has condemned this type, the essential features of which we shall point out farther on (257); but the principle once admitted, the relative smallness of the diameter was warranted.

The wisest course, and it is that always adopted in engines with the wheels free, is to let the leading wheels simply carry, and to give them a small diameter, a guarantee of stability (without excess, however, for there is another thing to be avoided: the heating of the journals), giving a large diameter to the driving-wheels, and consequently to the parts of the machinery a lowness of speed, which is very favourable to their wear.

These principles are doubtless departed from, when in a high-speed engine, having the driving axle in the middle, it is desired to make use of the adhesion of the leading-wheels, which must then have the same diameter as the principal driving wheels: the *Lyons* line employed during several years, engines with the front wheels coupled, having of course, like those in the middle, a diameter of 5 ft, 90. It has never been stated that these engines were more subject to get off the line than others; but it would not be prudent, particularly if the permanent way did not happen to be in good order, to much exceed this limit of 5 ft, 90; and if it is judged necessary to make use of the adhesion of another pair of wheels, it is preferable, when a question of high speed, to take the trailing axle, keeping the front one with small wheels. For ordinary speeds, coupling the front wheels has some advantages. The Northern of France has had built by the *Fives-Lille* company, 36 engines of this pattern, with wheels of 5 ft, 90. The hind-axle, with 4 feet wheels was placed under the fire-box. The engine with a heating surface of 993 sq.ft, 33, weighs filled, 30 tns, 80, distributed as follows:

Front	11,30	adherent weight 22,80 tons.
Centre (driving)	11,50	
Hind	8,00	

With coupling behind, the adherent weight could not reach so high a figure, because a load of 8 tons, sufficient for the hind axle, would be too little for the front. Empty this engine weighs 27 tns, 50 or 57 lbs per square foot of heating surface: a low figure with regard to the very moderate length of the tubes, 12 ft, 47, and to the weight of the great wheels.

248. *Driving axle behind.* — In sixwheeled engines, it is almost always the middle axle which is driving; always brought near the centre of gravity, it can take a considerable load, a useful property for engines with uncoupled wheels, but which the drivers abuse at times, in carrying that

load to more than is required for adhesion; the tyres and the permanent way suffer for it, but that is the least of the disadvantages: the most serious is that the stability of the engine is compromised. It is easy, of course, to avoid this danger, and so by coupling the springs together, rendering the distribution of the weight invariable.

The hind axle, as well as the middle one, can be taken as the driving one. But the little convergent play allowed when it is simply a carrying axle, must then be suppressed, as of course when it is simply coupled. There are two axles in an engine, to which no play can be given in this way: the leading axle, because it has to guide the engine; and the driving axle, whatever may be its position, besides, because the guard plates have to keep it at a rigorously invariable distance from the cylinders, on plan. The hind axle, when it only carries, may have, in the same way as carriage and waggon-axles, not only a longitudinal play (applicable also to the two others as we shall see), but also a convergent play, which facilitates running through curves. In low speed engines, and consequently with small wheels all of the same diameter and coupled, this consideration disappears, and the short distance between centres sometimes leads the hind axle to be driving.

Driving the hind axle may also be warranted in engines with uncoupled wheels. This position was the characteristic feature of one of *Stephenson's* first passenger types, a type dating from 1846, and remarkable in many respects. The fire-box overhanging, that axle, applied against it, was near enough to the centre of gravity, to receive the load required for adhesion, and more, and the more so, as the cylinders, outside, had been brought from their usual position at the smoke-box, up against the sides of the boiler. Besides its influence on the position of the centre of gravity this displacement reduced the length of the connecting-rod, which without that would have been excessive on account of the great length of the boiler. With rods too short, the effects of the obliquity are excessive; but, on the other hand, if they are too long they are too heavy (particularly as their section increases very rapidly with their length), and too difficult to handle in case of accident during running; and they require too heavy counterbalance weights.

Engines of this type have been prevalent enough in England; they have been at work in Belgium on the line from *Antwerp* to *Ghent;* it is also to an analogous type that has been applied the particular method of balancing, by a double moving apparatus on each side of the pieces which have a relative movement, as the Austrian *Staats Bahn* (Pl. LXXVIII, *figs.* 7 and 8).

In some cases the cylinders are on the contrary, brought in front of the boiler, as in the coupled engine, already mentioned, of the Western of

France. A glance over plates XXXIII and XXXIV is sufficient to understand the motives of this arrangement. The overhanging position of the fire-box, the large diameter (6 ft, 27), and the coupling of the hind wheels, have had the effect of pushing the leading axle forward, and particularly, the cylinders. Fault is found with this engine, and not without cause, for the smallness of the load on the front wheels (8 tns, 25); and it would have been smaller still but for the extreme position of the cylinders; a very moderate load was, it is true, the necessary consequence of the smallness of the wheels (3 ft, 67), but it would have been better to increase both the diameter and the load. It is true that this was scarcely possible with the fire-box overhanging, excepting by lengthening the barrel of the boiler; and beyond 13 feet the increase of heating surface gained by lengthening the tubes is pretty much an illusion. For my part, I see little else in that extra length than ballast in the front, but ballast that would not be owned to, and that it would be far better to apply openly.

249. *Crampton's engine.* — *Crampton's* engine offers a remarkable example of the position of the driving-axle behind. But its essential feature consists in that axle being behind the fire-box instead of in front thereof. Thence result a considerable advantage for high speed engines, but also serious drawbacks. The advantage is, that the boiler being no longer placed above the driving axle, a large diameter of driving wheels can be combined with a low centre of gravity; a circumstance which is favourable, whatever may be said, to stability, to the steadiness of outside cylinder engines, especially on entering curves. The distribution of the suspended weight, brought principally on the two extreme axles, tends to the same result. The height of the boiler above the rails being fixed, the diameter of the wheel is only limited by this one condition: that the axle is just low enough to clear the fire-door. The body of the axle which of course projects above the foot-plate, is covered with a sheet-iron casing to prevent accidents.

The drawbacks are: 1. the absolute rigidity and great length of the wheel base (16 feet in the Northern of France *Crampton's*, 15 feet in the *Méditerranée* ones) and consequent difficulty in passing, even through very moderate curves;

2. The great distance of the driving-axle from the centre of gravity, and consequently the comparatively small load that can be put on that axle. As in the engines mentioned just now (248) this drawback is reduced by the displacement of the cylinders brought backwards. But this displacement has a limit: for the connecting rods must have sufficient length.

The following is the normal distribution of the weight of the *Méditerranée Crampton's*, with heating surface of 1.038 square feet, and cylinders 1 ft, 31 $\times$ 1 ft, 97:

Engine filled.	Leading	12,00	30,19 tons.
	Middle...........	6,19	
	Hind (driving).....	12,00	

For the English engine from the *Creusot* works (Pl. XXII and XXIII) the builders give:

Engine filled.	Front........................	10,10	32,50 tons.
	Middle (driving)	11,40	
	Hind...........................	11,00	

But this is little in accordance with English practice; and it is all the more probable that the real distribution differs very much from this, as the drivers have great latitude in this respect, of which they take advantage. Examples of this kind prove nothing, then, and may not be objected to the only too self evident insufficience, of the adhesion, in *Crampton's* engine. It might doubtless be increased, by reducing the load on the middle axle still farther. But this means is not available, because to a certain increase of the load on the driving axle, corresponds an equal increase on the leading axle, and if the first had the load necessary for adhesion, the second carrying the same amount would be loaded too much, and would be always heating, on account of the much less diameter of its wheels. It is the reverse in the English engine. If the load on the driving axle increases, that on the other two diminishes. The distances between the centres are: 7 feet for the leading, and 8 feet for the trailing; if then an excess of load of p lbs is brought on the middle axle, the leading one gives $p \times \frac{8}{15} = 0{,}53p$, and the trailing: $0{,}47p$. If $p = 2{,}00$ tons, the distribution becomes:

Front	9,04
Middle (driving)............................	13,40
Hind	10,06

It is preferable to the preceding, and much more probable, as that is too much sparing on the adhesion. If p were considerably over 2,00 tons, the load in front would be too slight, and consequently the stability compromised.

250. *Want of adhesion at starting with Crampton's engine.* — It is not, as need scarcely be said, when an express engine with uncoupled wheels

is running at the velocities for which it is specially made that its adhesion fails; but when it has to develop a considerable effort of traction, at a lower speed, that is to say, going up inclines, although slight (it cannot manage any others), and at starting (211); the acceleration is too slow, the engine takes too long to get up speed.

Such is especially the fault of the *Crampton* engine; its starting is sluggish, a drawback which could only be avoided by overloading the leading axle (249). There is thus at each stoppage, or simply at each time of slackening speed, a loss of time, which is the more disadvantageous, as it is with trains for which time is most precious. It is true that express trains stop at very much fewer stations; but they have stoppages enough, for their slow starting to appreciably affect their thorough velocity. They are subjected besides like other trains, and more so, to slacken at junctions, which becomes daily increased by the construction of new branches.

It is in order to reduce this slowness in starting that the Northern of France put a large cast iron cross beam on behind to their *Crampton's:* an expedient of which we shall see numerous examples as a remedy for defective distribution of weight, and which has nothing in common with the pretended increase, so often alleged to, in the total weight of engines, with a view to adhesion. This increase is in general insignificant; it is a question simply of a counter-balance weight, which, bringing the centre of gravity nearer the driving axle, allows the load on the latter to be increased.

This expedient may suffice on lines with ordinary gradients, the insufficience of the adhesion being hardly manifest except at starting. It is not the same thing on gradients somewhat steep, which the engine could not manage with its normal load (unless it were slight, and the power of the engine therefore not utilised) only under the condition of effecting the conversion of the velocity into effort, within limits for which the small available adhesion does not leave sufficient margin. It is thus that the *Crampton* engines adopted for a long time for the express trains between *Paris* and *Lyons*, had to give place at the very outset to engines with greater adherent weight, on the section from *Tonnerre* to *Dijon*, which passes over the crest of *Blaisy*, separating the basins of the Atlantic and the Mediterranean, with long gradients of one in 125. *Crampton* engines, of the same type as the Mediterranée ones, are sufficient for the express service from *Paris* to *Nancy*, which at *Lérouville* presents the same conditions as to gradients as at the *Blaisy* crossing; but this is evidently a question of load, and the trains are less on the Eastern than on the Northern of France, and especially than on the *Méditerranée* lines.

The *Crampton* engines were given upon these last in 1870. They were replaced by engines of great adherent weight, spread over two axles, founded on those which for many years have done the work of the heavy sections of the *Orleans* lines. (Pl. XXV to XXVII).

These *Crampton* engines besides did not only want adhesion; they had become too weak for the always increasing loads of the expresses. The power could have been increased, at the same time sticking to the type, but the adhesion would always have failed, the load on one single axle being limited, and should be so as much as possible, the greater the velocity. In spreading the weight over two pair of wheels, the necessary adhesion is amply obtained, without undue strain on the tyres and rails. The Méditerranée has handed over a portion of its *Crampton's* to other companies. It makes use of the *Crampton's* which it could not get rid of, and of the old English engines with the driving wheel in the middle, on those portions of the Southern section where the gradients are good and the loads moderate. But engines with uncoupled wheels are henceforth excluded in principle, and in a not distant future will have altogether disappeared. This tendence is moreover general: it is one of the most striking facts of late years as regards traction,.

The principal features of the *Crampton* engine are to be found, in the United-States, for example, but as very rare exceptions, where they are combined with the distinctive point in American engines, that is to say a locking frame in front. In this case the driving axle is not precisely at the end of the boiler, but let in to the fire-box, by means of a double partition (Pl. LXXVIII, *fig.* 13); not being so far from the centre of gravity, it can be loaded more. It is to point out this that we mention at this time, an engine arranged with a view to sharp curves.

251. *Engines with driving axles without wheels.* — Placed behind the boiler, the driving axle of the *Crampton* engine can only be worked by outside cranks and connecting rods. If this position of the driving axle has to be combined with inside cylinders, there must be an intermedium. This is an intermediate shaft taking the connecting rods by inside cranks, and conveying the movement to the driving axle by means of outside cranks and connecting rods, that is to say the ordinary coupling arrangement (253). But the cylinders being horizontal the intermediate axle is on the same level as the driving axle, and the latter cannot then be any higher than the lowest point of the barrel of the boiler; thus is lost one of the advantages, indeed the distinctive feature of the system, which then becomes simply

an engine with the driving axle in the middle and hind wheels coupled, with the wheels and bearing springs of the cranked axle taken away.

This arrangement, first applied by *Robert Stephenson*, presents some advantages peculiar to itself. In ordinary engines, the driving axle has not an invariable position with respect to the cylinders, which, solidly united to the frame, participate alone in the oscillations of the bearing springs. With the intermediate axle, solidly fixed like the cylinders, upon the frame, the conditions are the same as in fixed engines, and the distribution of the steam is withdrawn from a source of irregularity, the influence of which is not at all trifling, in spite of the stiffness of the springs. The cranked axle, bearing no load, is besides less liable to break, and therefore is likely to last longer. In any case, however, the advantage is not marked enough to warrant a complication which is none the more justified by the position of the cylinders inside.

Wöhlert of *Berlin* built some engines of this type for the line from *Aix-la-Chapelle* to *la Ruhr*. The South eastern also adopted it, in spite of the coldness with which the *Crampton* engine pure and simple, which is derived from it and which is certainly much better, was received in England; but has in no case come seriously in practice, in this form.

The intermediate axle has been introduced into some engines with coupled wheels.

An example of this is to be found in a fourwheeled type constructed by the *Couillet* works (Belgium) for coal lines (Pl. XX, *figs*. 2 and 3).

Heating surface.	Tubes	612 feet.	673 square feet.
	Firebox	61 "	

Pistons 1 ft,15 × 1 ft,50, — wheels 3 ft,94, — between centres 8 ft,86

Weight: empty 19 tns,05 — full	Leading	11,48	23 tns,20
	Hind	11,72	

Capacity of the tanks.	Water	2,00 tons.
	Coal	0,40 "
Tractive force		3,00 "

An intermediate longitudinal with a bearing with horizontal adjustment, keeps the cranked axle in place.

It is asserted that the relative invariability of the position of the machinery obtained by the introduction of the intermediate axle, renders the maintenance simpler and easier; which would in effect enter into consideration for engines placed as these are in the hands of less efficient and less careful men. But it is difficult to see how the complication, the addition of new

moving parts, can really have the effect of simplifying the maintenance.

"When", it is said, "the tyres are worn out, replacing the wheels is a very simple operation, the axles carrying no portion of the machinery".

But besides the complication, there is the increase of weight. Now, when a tank engine is required of a certain power with only four wheels, the weight must be very closely looked after, and we come to here a high figure for permanent ways which are not very flourishing. It is added that all the parts placed to the inside are protected from the shocks to which the engines of colliery lines are exposed; that is true, but has nothing to do with the intermediate axle.

The adhesion was taken at $\frac{1}{7}$, because it is said, "of the relatively small adhesion on colliery lines". This figure does not make much of an allowance for the relative smallness foreseen.

§ VII. — Diameter of the driving wheels.

252. This element has varied greatly. If high speed engines ought to have large wheels, their diameter must however not be carried to excess. If the movement of the machinery is slow enough, there is then no motive for reducing it further, while the increase of the diameter of the wheels increases their weight, and raises the boiler too high, unless in the case of the *Crampton* engines, which are subject at the same time to grave objections (250). Thus experience has done justice to the excesses which were at first indulged in; so that while the velocity went on increasing, the diameter of the driving-wheels diminished. In France, after having adopted 7 ft, 55 in the *Crampton's* of the Eastern, 6 ft,89 was come down to, the figure in the engines of the same type of the *Méditerranée*, and Northern of France; it has been adhered to in the express engines of the latter line; in England, after having been as high as 9 feet (*Bristol* and *Exeter*), 8 feet (*Caledonian, South eastern, South western*) 7 ft, 5 (*Stockton* and *Darlington*) etc., 7 feet is generally adopted now-a days for uncoupled engines (*Great Eastern* engine, Pls. XXII and XXIII), or a figure very close; for coupled wheels, 5 ft,64 is often considered enough (*North London, Metropolitan*), and even 5 ft, 50 (Ireland) etc.

The United States themselves gave way to this excess which was little warranted by the speed of their trains, and they have got out of it again. To diameters of 8 feet, then 7 feet, have succeeded very moderate figures, such as 6 feet, and now-a-days, 5 ft, 50 to 5 ft, 57, which very generally prevail for passenger engines; and many engines with larger wheels have been brought down

to this diameter. The principal object of this substitution has often been to make the starting easier, by correcting an error in proportions, the cylinders being too small for the original diameter of the wheels. Large wheels require voluminous cylinders. At equal mean pressures in the cylinders, the tractive effort is proportional to $\frac{d^2 l}{D}$; if D increases, $d^2 l$ must increase of course in the same ratio. On the other hand for the same velocity of translation, the velocity of rotation of the driving axle, and that of the pistons diminish in inverse ratio to D, which is only advantageous to a certain limit, a considerable enough number of beats in the unit of time being an essential condition of the evaporative power of the boiler. This is one of the causes of the reaction which has taken place in the minds of many engineers against wheels of large diameters. For the same stroke, the effort of traction is the same, for example, for a piston of 1 ft, 19 diameter, with wheels of 5 feet, and for 1 ft, 50 diameter, and 8 feet wheels, while the number of revolutions, and consequently of blasts are as 1,60 to 1.

Only experience — and that is not very easy, on account of the complication of the elements entering, can indicate the point suitable to be adopted between these very wide limits; it may therefore easily be conceived what discrepances are still found to exist, at equal power, between the correlative dimensions of the cylinders and wheels in high speed engines. But very great diameters, that is to say, exceeding 7 feet, are almost generally given up, and small diameters are pretty frequent. On the *Manchester, Sheffield* and *Lincolnshire* line, where there are, it is true, very steep gradients, Mr *Sacré* works the expresses at a speed 40 miles an hour, with engines with four wheels coupled, 5 ft, 50 in diameter. These run very well, and their maintenance is light; the velocity of the parts of the machinery is not therefore excessive.

§ VIII. — **Number of axles driven.**

253. *Coupling.* — The adhesion due to a single axle is limited; the preservation of the rails and tyres does not allow a maximum load to be exceeded, which is agreed upon (243) to be fixed as nearly as possible at 6,5 tons per wheel. The complete independence which generally exists between the permanent-way and rolling-stock departments had for a long time very injurious effects on the rails. To obtain amply the adhesion they required, the locomotive engineers overloaded the driving axle without

scruple, to the great detriment of the permanent way, the wear and tear of which became excessive, without the principal cause being at once assignable for such excess, towards which the increase of the traffic and the indifferent quality of the rails helped. It was the rapid wear and tear, and the frequent crushing of the tyres themselves, facts which directly affected the locomotive department, that first gave the alarm, and brought about the determination to give up excessive loads, more injurious still to the rails than to the tyres.

But the limit of 6 tns,50 is not always possible for the present powerful engines with uncoupled wheels, which often require an effort of traction superior to $\frac{13,00}{7} = 1$ tn,85. In England particularly, the statical load on the rails often reaches 14 and even 15 tons. It is only, let us bear in mind, in the view of starting, and of working on light inclines up which they can take normal load up, that there is any necessity for great attention to the adhesion of high speed engines (250). Once started on a pretty horizontal line, at 40 or 50 miles an hour, the effort of traction which they can exert at those speeds is far below their adhesion. But for engines of mean speed, and *a fortiori* of low speed, the adhesion due to the load of a single pair of wheels would be absolutely and constantly insufficient; that of several pairs of wheels or even of all is then necessary.

Nothing is simpler in principle; but also nothing more troublesome at times, more difficult as regards curves, than the means employed to convey the motion of the driving-wheels to one or several other pairs.

Two wheels placed in the same plane, being attached to each other by a connecting rod working on two equal and parallel cranks, it is evident that the one of the wheels receiving a movement of rotation will transmit that movement to the other, the rod moving in a direction parallel to itself, and all its points describing the same circumference as the centres of the crank pins.

Of course for two pairs of wheels, the coupling apparatus, double like the machinery, is outside the wheels, and the cranks fixed at an angle of 90° to each other.

Theoretically, a rigid rod can convey motion to as many axles as may be wished; but, in fact the engine does not run on a perfectly plane surface; the line of the centres, like that of the points of contact on the rails, is broken at each moment, following the inequalities of the rails. The line of the crank pins must also therefore be able to yield, and consequently the connecting rod must be provided with joints, or replaced by several separate rods, placed in that case in different vertical planes, and joining the crank-pins together two and two. The joint is more used (*o*, *o*, *o*, Pls.

XXXVIII, XLIII, XLVI, XLVIII, XLIX, LIII, LV, etc.). A single one is enough for three axles; two for four axles, three for five, etc.

254. *Relation between the position of the cylinders and that of the coupling cranks.* — In outside cylinder engines the driving-crank acts necessarily as coupling crank. To be otherwise, it would be necessary to crank the axles, so as to apply the connecting rods to these cranks. With inside cylinders the driving crank can also act as coupling crank, but on condition of cranking the axles to which the rotation has to be conveyed. It is evidently much simpler to place as in the first case, the coupling apparatus outside the wheels; the driving-axle then has its special coupling cranks; and there are consequently two cranks more with inside cylinders than with outside ones. The outside cranks are placed, besides, in the first case, at 180° to the driving cranks; a notable advantage, as will be seen, from the point of view of the disturbing influence of the parts having relative movements.

255. *Disadvantages of coupling.* — The equality of the movements of rotation requires the equality of the diameters of the coupled wheels. This condition is no drawback in itself for slow speed engines, all the wheels being then of small diameter, which allows, on the one hand, as we have seen, greater width to be given to the boiler, and on the other hand, the axles to be placed under the boiler, in such a manner as to distribute the weight most favourably, without making any exception as to the position of an axle under the fire-box, when the latter goes very little below the barrel of the boiler, according to the arrangement more and more used since coke has been replaced by coal.

But the condition of the equality of diameters has a drawback; perfectly fulfilled in an engine just come out of the shops with its wheels freshly turned up, it soon ceases to be so in consequence of the inevitable want of homogeneity and hardness of the tyres, and the inequality of the loads; and once an inequality of diameters appears, slipping comes in, the effects react on and aggravate the cause. The engine acts on the rails so to say, as a planing machine; one wheel worn down more than another involves the turning down of the whole set, so that the amount of the evil rapidly increases with the number of wheels. As happens in the case of all points not yet cleared up by special and conclusive experiments, engineers are not yet agreed as to the extent of this drawback. One of the simplest and most direct means of getting the measure of them, is to verify, under the same conditions of gradients and curves, velocity, and state of the atmo-

sphere, the consumption of engines differing only by the number of their wheels coupled, or by the amount of wear of their tyres, and running without load.

Although preferred to separate rods, the joint gives rise to one objection. If (Pl. LXXVIII, fig. 16) the connecting rod *b* which carries the joint, breaks or has to be taken off for any cause, the other one *b′* works, and all that is lost is the adhesion of the axle A. But if it is *b′* which is damaged, *b* being no longer rigid, can not work, and must be taken down also.

An objection of an analogous nature arises against the position of the driving axle behind, in engines with six wheels coupled. As the same connecting rod then conveys the rotatory motion to the two carrying axles, any accident to this rod reduces the adhesion of the engine to that of one single pair of wheels. It is evidently preferable that the axle of the latter, placed in the middle, should distribute the motion on each side.

256. It has been tried to be got rid of the disadvantages of permanent coupling by means of rods, and to make the adhesion of the carrying wheels available when required, by a friction gearing, that is to say, a roller more or less tightened by a screw, between one of the driving and one of the carrying wheels. M. de *Pambour* (*) in 1840, quoted trials which had already then been made in this direction by Mr *Melling*. They were renewed later on, on the *Great Western*, and it is said with success. They did not, however, lead to any application of the apparatus.

Mr *Livesey* has also proposed a mode of transmission, requiring neither the invariable parallelism, nor the equality of the diameters of the wheels, but always requiring the invariability of those diameters, unless by involving considerable passive resistances. We shall return to this when we speak of the process tried by *Norris*, then by M. *Maffeï*, of which *Livesey's* is only a variation.

257. *Passenger engines with four cylinders of the Northern of France.* — When it is only a question of two driving axles, coupling can actually be avoided, but not without great complication. One single attempt has been made in this direction, and with very little success. When the Northern of France began to realise the insufficience of their *Crampton* engines, the

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(*) *Traité des locomotives,* 2nd edition, p. 490.

coupling of the second axle was rejected in principle; the breaking of the rods was feared, it was said. Examples to the contrary were not however wanting, and among others that of the *London* and *Birmingham*, upon which engines with four wheels coupled had long been running express trains without accidents. It is the same thing on the Great Northern, which adopts engines with the hind wheels 7 feet in diameter, placed behind the fire-box, and consequently requiring very long rods, for their high speed trains. These engines have inside cylinders, double frame, the inside one of iron, the outside of wood; the cranked axle has double journals.

In spite of these precedents, and yielding, besides, to the praiseworthy desire to do something new, the locomotive engineers of the Northern of France had decided on two driving axles, each driven by a pair of outside cylinders (Pl. LXXVIII, *fig.* 5). These driving axles were the two extreme ones; their normal load was regulated in accordance with the requirements of adhesion; and from the total weight of the engine, which carried its own supplies, was derived the number of intermediate bearing axles; this was fixed at three. The leading axle being the driving one, prudence required that the diameter of the wheels should be very limited (247), the more so as it was a question of a type of engine which should, according to the views of its designers, run at a high speed. A point was made also of reducing the relative weight as much as possible, and it was requisite again from this point of view, to reduce the diameter of the wheels, 5 ft,25 was adopted.

The objection which arises at first sight, against this solution, is the complication involved by the double moving machinery; on the other hand, from the enforced smallness of diameter of the driving wheels results the necessity of also much reducing the stroke of the pistons, which with an ordinary stroke would take excessive velocities, and of giving them instead a large diameter; this is greater than the stroke (1 ft,18 to 1 ft,11) an unfavourable proportion, and one which renders the influence of the clearance excessive. Moreover, the number of revolutions, and consequently the number of strokes of the piston in the unit of time exceed the suitable limit. From this point of view, it would have been preferable to place the two pairs of driving wheels in the middle, and the carrying wheels at the ends; but an even number of carrying wheels would then have been required, and consequently four, if two were not sufficient. With two only, we should have, as to general arrangement, the high speed engine of the Russian lines (Pl. LXXVIII, *figs.* 14 and 15), or rather there was only one step required to arrive at those: to replace the double machinery by coupling, so evidently suitable by the closeness of the driving-wheels. This approxima-

tion of the two types, suffices to show that progress was being sought along the wrong road.

Besides these inherent errors in principle, experience brought to light others, in execution; thus the boxes of the carrying axles frequently heated, on account of the excessive velocity of their great journals. But above all was the entrance on to curves, which was of extreme difficulty and even dangerous at high speeds, on account of the great length of wheel base (17 ft, 12) and the height of the centre of gravity. Altogether, these engines were unfit for the work they were intended for; they were obliged to be employed for ordinary trains, and the questions of the working the expresses taken up anew. *Noon had been looked for*, as they say, *at fourteen o'clock* (*sic*) while the coupling of the two axles, offered a complete solution, warranted by experience. There was nothing better to be done but to return to that, which was done (Pls. XXX to XXXI).

We subjoin here the principal elements of three recent types of engines for high speeds and with four wheels coupled, those of the *Orleans*, *Méditerranée*, and Northern of France.

LINE.	HEATING surface.			Effective normal pressure.	PISTON.		Diameter of the wheels coupled at contact.	Distance between extreme centres.	Weight empty.	WEIGHT with 8 inches of water over the fire-box.				Observations.
	Fire-box.	Tubes.	Total.		Diameter.	Stroke.				Front.	Middle.	Hind.	Total.	
	sq. ft.	sq.ft.	sq.ft.	at.	ft.	ft.	ft.	feet.	tons.	tons.	tons.	tons.	tons.	
Orléans.......	87,51	1386	1474	8,0	1,41	2,13	6,63	13,12	30.00	9,70	12.15	12.15	34.00	(1)
Paris - Méditerranée.......	80,51	1266	1346	7,5	1,44	2,13	6,56	13,12	30.85	9.61	12.72	12.42	34.75	(2)
Nord (Kœchlin).	107,64	943	1051	9,0	1,42	2,06	6,89	18,00	32.57	10.10	14.00	11.50	35.61	(3)

(1) Tubes of 16 ft, 4. | (2) Tubes of 15 ft, 28. | (3) Tubes of 10 ft, 39.

It will be remarked how small relatively is the heating surface of the Northern of France engine; but it is clear that with its large fire-box, and its tubes of 10 ft, 39 only it is, as regards the production of steam per unit of surface, in much more favourable conditions than the others with their smaller fire-boxes and longer tubes. The wheel base is very long, longer again than that of the four cylinder engines, and is thus very perceptible on curves with this engine, the running of which on the straight is however very steady.

The distribution of the weight in this engine does not seem to be very satisfactory. On the one hand, with excess of adhesion, why admit so high a figure as 14 tons? On the other hand, why admit a difference of 2 tns,50 between two pairs of coupled wheels? The load on the leading pair of wheels was of course kept down, to avoid heating; but with their diameter of 4 ft,30, they could certainly carry more. Taking away for example, 2 tons from the driving axle, following distribution could be made :

Front, 11,045; driving, 12,000; hind, 12,565 tons; which would probably be better.

258. *Engines with more than six wheels coupled.* — It is a long time now since the number of axles in uncoupled engines exceeded three. Without speaking of the United States, where the bogie frame with two axles ought only to count for one, and where the weakness of the permanent way leads to a greater multiplication of the points of support than in Europe, Mr, now Sir *Daniel Gooch* constructed high speed engines for the *Great Western*, weighing 35 tons, with eight wheels, two pairs of which were in front of the driving axles, and one behind the fire-box; and Mr *Mc Connell* arrived at a similar type by applying an axle behind the fire-box of engines with driving wheels behind, and *Stephenson's* overhanging box (248). But coupling more than six wheels is still recent in Europe; many lines even of very great traffic, as that from *Paris* to *Marseilles*, still stick to sixwheeled engines, which are sufficient when the gradients are flat. More powerful engines would run more rarely with full loads, and would in that case be less efficiently utilised; the length of the trains would become excessive particularly with empty vehicles; the sidings would have to be lengthened; the strains on the couplings would be greater, and their breakages more frequent. Such are in a few words, the motives which have determined the *Méditerranée* company for example, to reject large engines, on the greater part of its system of lines. These motives are well founded, without however being absolute; and it is quite to be understood how other companies, the Northern of France for example, should have been led to adopt something different, in spite of the generally favourable nature of their lines.

For gradients only, there is no need to adopt any more powerful engines than the sixwheeled ones, unless the inclination be very considerable, one in 50 at least, and when moreover, the conditions of traffic require very heavy trains. Thus the longest and steepest gradient which at present exists on the French lines (one in 32) from *Capvern* to *Montréjeau* on the line from *Bayonne* to *Toulouse*, is worked by simple sixwheeled engines,

while engines with eight wheels coupled are put by the same company on to the heavy wine trains, on the line from *Toulouse* to *Cette*, which has very flat gradients.

It is not in fact, a question only of gradients, but also, if it be not altogether, a question of traffic; and especially from this latter point of view it may be resolved in different ways, as is proved by the examples of the *Méditerranée* lines on one side and the Northern and *Midi* of France on the other. On lines with flat gradients, there is no question of an engine behind, all the moving power is concentrated at the head of the train; a choice must be made between relatively light and heavy trains; and if the latter be decided on, between double traction, or one engine with double power: points greatly controverted, and to which we shall soon return (263).

Admitting a load of 14 tons on an axle, which is considerable even at a low speed, and a uniform distribution of the load, 42 tons is the maximum weight of a sixwheeled engine, and taking adhesion at $\frac{1}{7}$, 6 tns,00 is the maximum tractive power it can exert. If a more considerable effort of traction is required, by reason of the gradients and the traffic, it is not essential to have recourse to a more powerful type on that account. Without entering just now into the discussion of the advantages and drawbacks of double traction considered in general, such guarantees of safety, are presented on steep gradients by putting one of the engines behind, that far from trying to be avoided, it ought on the contrary to be put down as an absolute condition, at any rate for goods trains. It is true that if the deficiency of a single engine, by reason of the gradient, were inconsiderable, the auxiliary engine would be only very partially utilised; but that is one of the difficulties of detail which constantly occur in working railways, and which are always overcome by proper organisation, and a judicious rearrangement of the making-up of the trains.

On the *Méditerranée* lines, where the ruling principle is in full force of the position of the auxiliary engine behind the train on the gradients where such aid is necessary, the sixwheeled engine remains the normal one, as far as two of these engines suffice ordinarily. It is only beyond that, that a more powerful one is admitted. To reduce the weight of the trains would be, in general, objectionable; trains too light and therefore too numerous cause generally expensive working.

It is in this way that the necessity for a new more powerful type has not been felt on the lines in question, excepting for the main line from *Paris* to *Nimes* by *Brioude* and *Alais* a line with very long gradients of one in 40

opened for traffic in 1870; then for the section from *Chambery* to *Modane*, one in 33, opened only at the end of 1871. On the first, the whole of the conditions of the traffic led 400 tons to be adopted for the normal composition of the trains to be drawn; gravity alone for such a train would require an effort of traction of 10 tons. This was a state of affairs that put two sixwheeled engines out of the reckoning, even of the most powerful, with 1200 square feet of heating surface, weighing with their tenders 113 tns, 5, that is:

	TONS.
Two engines..................	$2 \times 34,10$
Two tenders full	$2 \times 22,65$
	113,50

and the tractive effect of which reaches at most to $\frac{2 \times 34 \text{ tns}, 10}{7} = 9 \text{ tns}, 70.$

Sixwheeled engines constructed *ad hoc*, and with the effort of traction carried to its extreme limit: 6 tons, would be still far too low, particularly taking into account the stiffness of the curves, which go down as low as 650 feet radius.

On other points on the same lines, the ordinary sixwheeled engine is sufficient, in spite of the steep gradients: one in 50 on the line from *Dôle* to *Pontarlier*; one in 39 on the line from *Lyons* to *Roanne* by *Tarare;* it is, we repeat again, a question of traffic. Which does not mean of course, either that the power of the sixwheeled engines is always utilised on these lines, or that it is always sufficient; the elements of the traffic are by no means constant enough; and that would be so even were there nothing but atmospheric influences. This is got over then, by adding a third engine when needed; on this point we shall have more to say, besides, when treating specially of traction on inclines.

All the French lines excepting the Western of France, have now-a-days eight wheels coupled engines. They are numerous enough in Germany, in Austria; they are to be found also, but few, in England, particularly on the *Great Northern*. At last, too, they have made their way into Belgium; since the end of 1871, they have definitively replaced the fixed engines for goods train on the *Liége* inclined planes, on which for several years now (1866) the passenger trains have been drawn by locomotives with six wheels coupled.

The new type which is, as suits a steep incline (one in 36) and a short distance, a tank-engine, draws a normal load of 180 tons (200 at the maximum), at a speed of from 7,5 to 9,3 miles an hour.

The powerful 8 wheels coupled engine is recent in France, where it dates at any rate, from not before the alteration of the *Engerth* engine, in 1859; and yet the *Midi* had put into work, after the exhibition of 1856, a locomotive with eight wheels coupled (*Wien Raab*), constructed at the shops of the State lines, at *Vienna;* and three years afterwards, the Northern of France created the *fortes rampes* type, a tank engine with eight wheels of 3 ft, 48, and the boiler of which presents the same arrangements afterwards applied to the locomotive with twelve wheels (262). But as far back as 1854, *Ross Winans*, delivered to the *Baltimore* and *Ohio* line, the "*Centipede*," having four pairs of wheels all coupled, 3 ft, 57 in diameter, and a four wheeled truck in front. These twelve wheels were placed between the cylinders and the fire-box; the cylinders were 1 ft, 84 in diameter with an equal stroke; the tender had eight wheels; it was thus a twenty wheeled engine, in all.

The *Jeffersonville, Madison* and *Indianopolis line* has had since 1866 eight wheels coupled engines, with cylinders 1 ft, 67 $\times$ 2 feet, heating surface of $103 + 1237 = 1340$ square feet. With us, the weight corresponding to that heating surface does not require eight points of support, unless the engine has itself to carry a considerable supply of fuel and water, as the engine of the *Ceinture* (*Paris*) (Pls. LV to LVII) which has 4,80 tons of water in its tanks (which are only the contents, however, of a small tender), and 2,35 tons of coals. But we know that American lines, the permanent way of which is weak, have quite other requirements in the way of load per axle, than European lines.

The "*Centipede*" engine, which carries its supplies also, 6 tns, 50 of water, and 1 tn, 5 of coals, presents a peculiarity: the water tanks, placed sideways along the boiler, form an integral part of the frame: an arrangement analogous to that of *Krauss's* fourwheeled engine (244).

In the engine with eight wheels coupled, it is always the third axle which is driven. The second would be too near the cylinders, the more so that in these powerful engines with a stroke of 1 ft, 96 at least, short connecting rods would give too great an obliquity.

Of the three coupling rods, the middle one is then subjected to an effort of about double that of the end ones, a circumstance which should always be remembered in the section of the rod. The two joints are always placed on the two extreme rods, and not on the middle one.

259. *Examples of engines with eight wheels coupled.* — Engines with eight wheels coupled take a place in the working of the great lines, which

becomes more important daily. They must therefore be dwelt upon. They are represented in the atlas of plates by four types, those of the *Orléans* lines, of the *Northern of Spain*, of the *Moscow and Koursk* line, and the *Ceinture* of *Paris*. The following table brings together the principal elements of these engines, and of some others. These elements, altogether, vary little, unless in the length of the tubes.

Engines with eight wheels coupled.

	HEATING SURFACE.			EFFECTIVE NORMAL pressure.	PISTONS.		DIAMET. OF THE WHEELS at contact.	DISTANCE BETWEEN the extreme axles.	WEIGHT EMPTY.	WEIGHT with from 4 to 6 inches water on the fire-box roof.					OBSERVATIONS.
	Direct.	Indirect.	Total.		Diameter.	Stroke.				Front.	Second.	Third driving.	Fourth.	TOTAL.	
	sq. ft.	sq. ft.	sq. ft.	atm.	feet.	feet.	feet.	feet.	tons.	tons.	tons.	tons.	tons.	tons.	
Northern of France (Type *fortes rampes*) ..	107,7	1558 and 236 of the drier.	1903	8	1,57	1,57	3,49	»	33.500	11.000	11.200	11.200	11.600	45.000	(1)
Orléans (*Cail*)	111,9	2142	2254	»	1,64	2,13	4,22	»	37.500	»	»	»	»	43.000	(2)
Northern of Spain	107,9	1675	1783	»	1,64	2,16	4,26	13,54	39.000	10.750	10.750	11.850	10.750	43.500	(3)
Northern of France (*Fives-Lille*)	104,0	1658	1762	8	1,64	2,13	4,26	13,94	38.860	11.600	10.680	11.300	9.800	43.380	(4)
Eastern of France. (*Engerth* separated from the tender)	104,5	1980	2085	»	1,64	2,16	4,13	»	41.090	»	»	»	»	46.310	
Eastern of France. (*Graffenstaden*)	102,2	2075	2087	8	1,64	2,16	4,13	12,94	38.967 with 1 ton of ballast in front.	11.610	23.165		11.395	46.170	(5)
Midi (*Cail*)	113,8	2079	2193	»	»	»	4,26	13,58	37.850	10.200	10.100	12.500	11.200	44.000	(6)
Paris-Méditerranée (*Graffenstaden*)	104,5	2083	2188	9	1,64	2,16	4,13	13,17	44.800	12.150	12.150	13.450	13.450	51.200	(7)
Russian Railways (*Moscow Koursk*) (*Sigl.*)	104,2	1790	1894	8	1,68	2,09	3,93	12,75	43.500	11.500	12.500	13.000	12.000	49.000	(8)
Ceinture line (Tank engine) (*Kœchlin*)	95,6	1252	1348	7 ½	1,51	1,97	3,90	12,75	36.500	11.900	11.900	11.900	11.900	47.640	(9)
Belgian State lines. (Tank engine.) (*Malines* shops)	121,5	1358	1430	8	1,57	1,80	3,33	»	»	»	»	»	»	49.500	(10)

(1) Tubes 11 ft, 48 long.
(2) Tubes 16 ft, 78 long.
(3) Tubes 16 ft, 79 long.
(4) Tubes 13 ft, 45 long, hind axle under the fire-box.
(5) Tubes 16 ft, 40 long, overhanging fire-box.
(6) Tubes 16 feet, 72 inches long, takes 500 tons up 1 in 200.
(7) Tubes 17 ft, 58 long.
(8) Tubes 15 ft, 55 long; indicated load 600 tons at 28 miles an hour on a level, and at 9.5 miles up 1 in 125.
(9) Tubes 12 ft, 14 long.
(10) Tubes 12 ft, 85 long.

It will be remarked that, excepting the two tank engines, both loaded with a weight of about 7 tons of fuel and water, not including the weight of the tanks, the Northern of Spain engine has the least heating surface notwithstanding its long tubes, and the broad gauge of the line. The engineers of that line have not moreover taken advantage of the increase of gauge to establish more powerful engines. The engines they have however are quite powerful enough for the gradients and the traffic.

The *Ceinture* engine is not quite in its place on that little line, with its flat gradients. The reduction of dead weight which, on account of the suppression of the tender, carried to the utmost point, specially designates it, like the Belgian engine, for working steep gradients. It has been the object of some trials, with regard to this, the results of which will be mentioned in the chapter dealing traction on inclines.

260. *Engine with eight wheels coupled with intermediate driving shaft.* — The intermediate axle, which we have seen applied to uncoupled engines, and to four wheels coupled, has also been so to eight wheels coupled; for example to that designed by Mr *J. Edwards Wilson*, engineer-in-chief of the *Oudh and Rōhilkund* lines, for the *Lucknow* and *Caunpore* line, and constructed by *Sharp*, *Stewart*, of *Manchester* (Pl. LXXIX, *fig.* 6); the cylinders and the frames are inside; four coupling rods distribute on each side the motion to the axles, on both sides of the intermediate shaft, placed nearly in the middle. As in this case, there are in fact, five axles, three joints were necessary instead of two.

261. *Engines with ten wheels coupled.* — Eight wheels coupled are quite enough, and it would be prudent to stop at that number; however, it is true that ten wheels and even twelve have been gone to, exceptionally.

In this case again the example, if not the progress, has come from America. The first tenwheeled coupled engine, was constructed specially for the service of the *Madison* incline; it carries its supplies, concentrated in portion towards the hinder part; a fact which accounts for the distribution of the axles: three only in front of the fire-box, and two behind.

The pistons are 1 ft,69 in diameter, and have a stroke of 2,00 feet; the wheels are 3 ft,67 in diameter.

The length of the wheel-base is 21 ft,00.

Weight of the engine.	full.......	50	tons with 8 tons of water in the tanks.
	average...	48	

If this multiplicity of the points of support is without drawback, when it is a question of free wheels, it is quite another thing when all the wheels have to be coupled; and it is certainly to be regretted, as regards the available power of the machine, the preservation of the tyres and of the rails also, to set up on ten wheels an engine all the weight of which must be adherent, and which does not exceed 50 tons.

Messrs *Sharp, Stewart* and Co have also constructed for the heavy inclines of the Bhore Ghaut (*Great Indian Peninsular* Railway), engines with ten wheels with pistons 1 ft, 64 in diameter and 2,00 feet stroke, and weighing filled only 48 tons. The preceding observation applies then *a fortiori* to these engines, and the number of their wheels is less warranted by the fact that the Indian railways being constructed in the *English* and not in the *American* style, do not impose the restriction so low of limit of the load per pair of wheels. This is moreover what the engineers soon discovered; the type in question was given up before long and replaced by an other with eight wheels.

The *Orléans* has also made a trial of the tenwheeled coupled engine (Pls. LVIII to LX) for the crossing of the *Lioran* from *Murat* to *Aurillac*, with long inclines of one in 33, with numerous curves of 1000 feet, and where the service includes mixed trains running about 25 miles an hour, and goods-trains up to 150 tons, not including the engine, at from 9 to 12 miles an hour. The first are drawn by engines with eight wheels coupled; the second by the engines in question at this moment, but not in such a normal manner as assumed by the project.

The supplies of water being available almost everywhere on the line with ease and economy, a small quantity is sufficient even in the high expenditure per mile, and they were able to be put on the engine.

Heating surface.	Firebox............................	107,6	square feet.
	Tubes (16 ft,40 long, 1 inch,73 in diam.).	2152	"
	Total.............	2259,6	"

Pistons..........	1 ft,64 by 1 ft,97		
Wheels..........	3 ft,30, length of wheel-case 13 ft,86.		
Weight of the engine empty, with tools		47,85	tons.
Water in the boiler (0 ft,33 above fire box roof)		5,58	"
Water in the tanks..		5,40	"
Coal on the grate..		0,30	"
Coal in the bunker.		1,50	"
Weight at starting..........		60,63	"

Mean weight (supplies run out)	57,18 tons.
Minimum weight (in running)	53,75 "
Effort of traction, admission 50 per cent	7,98 "
Adhesion $\left(\text{at } \frac{1}{7}\right)$	7,675 "

The cylinders are outside; the frame which is inside for the three first axles, is outside for the two others, which allows the width of the fire-box to be increased, and the axle-boxes of the last axle placed under the long fire box, to be kept away from the fire.

In reality, the frame is double from the fourth axle, the two longitudinals, inside and outside, both continuing so as become solidly fastened together; but it is the second which brings the load on the axles. It is curved over the wheel, and the inside longitudinal is similarly shaped towards the upper part, which allows a continuous connection to be made between them, by means of a sort of cast-iron case with flanges, strongly fastened by bolts (Pl. LXXXVII, *fig.* 1). The driving axle is the middle one.

" The connecting rod taking the driving crank-pin between the two coupling-rods, only tends to break that pin under the action of the portion of force necessary to cause the middle pair of wheels to turn round."

This is from an autographic note emanating from the company:

" The two longitudinals," says on his side, the late M. *Bonnet* (*), are fastened together by cross pieces in front of the fourth pair of wheels toward the hind part of the engine, and this pair of wheels runs between the longitudinals, which form a double frame for this length. In this way, not only are the axle-boxes outside the grate, but the two coupling rods of the two hind wheels can be coupled outside the connecting rods, while the coupling rods of the two front axles are inside the connecting rods, and the reactions on the crank pin of the driving wheel balanced as much as possible."

It would seem then that the engine in question presents some peculiarity as regards the arrangement of the coupling rods, and that this peculiarity corresponds with the arrangement of the frame, inside at the front part, and outside behind.

There is nothing in this; the arrangement of the connecting and coupling-rods, is just what it is in outside cylinder engines, with six wheels coupled, and driving wheels in the middle, when the arrangement of the coupling-

(*) *Mémoire de la Société des ingénieurs civils*, 1869.

rods placed in a line with joints, is rejected, and separate rods then employed (253).

The front coupling rod must then be placed of course between the wheel and the connecting rod (unless an inclination be given to the cylinders, which is quite inadmissible) (273), and consequently the latter between the two coupling rods; and the relation between this way of placing the rods and the position outside of the frame behind is quite a secondary matter; it reduces itself to this, that the hind coupling cranks overhang less on account of the outside longitudinal, than simple crank pins set into the nave would make with an inside longitudiual. As to the strain on the pin of the driving wheel, the shearing effort which acts on it is only $P - 2p$, P being the effort exerted by the connecting rod, and p, that exerted by each of the coupling rods. The longitudinal strain on the extreme fibres, at the section of greatest strain, is:

$$R = \frac{4}{\pi r^3}\left[P(l + l') - p(2l + l' + l'')\right],$$

r being the radius of the pin, and l, l', l'' the respective distances between the wheel and the first rod, — the first and the second — the second and the third (Pl. XX, *fig.* 13). Admitting that the effort of traction T on the pistons is spread equally over the five pairs of wheels, equally loaded, we have, nearly,

$$P = 2{,}5p = \frac{T}{2}, \quad \text{whence} \quad R = \frac{4}{5}\frac{T}{\pi r^3}(0{,}5l + 1{,}5l' - l'').$$

This type, in spite of the positive merit of the carrying out, had but indifferent success. The load drawn by tenwheeled engines little exceeds that drawn by eightwheeled engines, and the allowance of fuel to the first is very much greater; and they pass besides, less easily through curves. Their sole advantage is a less tendency to slip, a natural consequence of their much greater weight, with a scarcely superior load, that is to say in reality of their faults. It is certain that drivers much prefer the eightwheeled engines; and, significative fact, only two tenwheeled engines have been constructed since the *Cantal*, the first of that type, made its appearance at the exhibition of 1867.

262. *Engines with twelve wheels coupled.* — This time again the example was given by America; but it has not been followed up. It was Mr *Millholland* who did not shrink from driving twelve coupled wheels by one single pair of pistons, in the tank-engines drawing coal-trains on the line

from *Reading* to *Philadelphia*, between *Port-Richmond* and the *Skuykill* (Pl. LXXIX, *fig.* 10).

Pistons 1 ft, 67 in diameter, and 2 ft, 16 stroke.

Wheels 2 ft, 95, length of wheel-base 19 ft, 68.

Heating surface 1.399 square feet only.

The fourth axle is the driving one. The water is stowed in three tanks, two sideways, and one on the fire-box, their total capacity is 1.000 gallons. Weight of the engine loaded: 44 tns, 75.

With an effective pressure of 5 tons 1/4 in the cylinders, the effort of traction measured on the pistons, that is to say including the fraction absorbed by the resistance of the machinery is 8 tns, 95, or the 1/5 of the weight.

Engine of the Northern of France. Admitting that an engine must be supported by six axles, by raison of its weight and the condition of the permanent way, and that the total adhesion is to be utilised, it is difficult to believe that driving twelve wheels by one pair of pistons is the best course to adopt. The division of the wheels into two independent groups, each driven separately, seems much preferable. This was carried out by the late M. *Petiet* in the Northern of France twelve wheels coupled engine, in which again reappears the general design of the four cylinder passenger-engine (257), but more powerful, and adapted to low speed traffic. It is (Pls. LXI and LXII) an engine with inside frame, carrying its fuel and water, and with two pairs of outside cylinders, each of which drives three coupled axles. It is thus a simple apparatus as regards the production of steam, but double as regards machinery. As to staff, this engine does not entirely possess the advantage often attributed to it compared with traction by two engines: it requires only one driver certainly, but with its great fire-box, an extra fireman is indispensable.

The twelvewheeled engine of the Northern of France has been very severely criticised.

English engineers particularly greeted it with astonishment, entirely unmingled with admiration. To my idea, this was not justified; if the passenger-engine with four cylinders (257) was, it must really be admitted a complete *fiasco*, — the goods type, leaving aside the question of the necessity of so powerful a machine — recommends itself by its really good qualities. The way in which English engineers stick to their types, which they quite look on as classic, their repugnance to what they call *colossal engines*, prevent them sometimes doing justice to the ingenuity, and perhaps the usefulness, of the attempts made to create new types, answering, more or less well of course, to new wants.

It has sometimes been adduced, that as regards slipping, the wheels coupled all together are preferable to their division in two groups. The grounds for this opinion are, that all the wheels together would resist slipping, while divided into two, each group could slip by itself; and if that happens to one of them, the coefficient of adhesion immediately diminishing for that group, the effort of traction is thrown in great part, on to the second group, which immediately, in its turn, commences to slip. This argument seems to fail at its very basis. If all the coupled wheels are in the same conditions of load and friction, none of them will slip, or all of them will slip, whether uniformly connected or not. If on the contrary, we admit that at a given moment certain of them have a greater tendency than the others to slip, that is to say if the effort of traction which they can transmit is reduced, the excess will come in the two cases on the others, which will also slip. There is only one point incontestable, and it is that the coupling together of the whole of the wheels involves an excess of slipping, by inequalities of diameters, and consequently of resistance to movement and of wear and tear.

In the engine with twelve wheels coupled of the Northern of France, as in the tenwheeled passenger-engine, and on analogous grounds, proportions of the cylinders are unfavourable.

The stroke is the same as the diameter, 1 ft, 44. This short stroke, and the consequent excess relatively of the diameter, were obligatory on account of the smallness of the wheels, 3 ft, 49, a figure which could hardly be perceptibly increased, for a point was very properly made of putting the fire-box not only above the axles, but above the wheels also, which allowed the fire-box to be much increased in width.

The first type of twelvewheeled engines, constructed in 1862, received in 1867, modifications which we shall only point out here in the abstract, for they have only reference to the boiler. The latter had in 1862 as essential features, short tubes and the addition of a reheater. In 1867, the length of the tubes was still more reduced (to 8 ft, 20), and a drier added to the heater.

In this way a most unusual proportion between the heating surface and the other elements of the engine has been arrived at. In the first type, this surface was 2296 square feet, including the heater; in the second, the heating surface proper is reduced to 1240 square feet (tubes 1137, fire-box 103), and the total surface is 1646 square feet, including 161 square feet for the drier, and 215 square feet for the heater. This is not the moment to discuss this boiler and its proportions; we may say however, at once, that experience has in no way brought out what was expected as to power and

economy of production; and that the engineers of the Northern of France had reason to regret having, in this case, gone from the proportions warranted by practice.

These are the weights of the two types :

	TYPE OF 1862.			TYPE OF 1867.		
		Distribution.			Distribution.	
	tons.		tons.	tons.		tons.
Engine empty........	44,50	1st axle....	9,20	46,20	1st axle....	9,90
Water (boiler)........	4,20	2nd —	9,20	3,50	2nd — ...	10,70
Water (tanks)........	8,00	3d —	9,20	8,00	3d —	8,90
Coal (fire)	50	4th —	10,70	40	4th —	19,20
Coal (bunkers).......	2,20	5th —	10,70	2,20	5th —	
Tools................	30	6th —	10,70	30	6th —	11,50
	59,70		59,70	60,60		60,20

Effort of traction measured on the pistons, with coefficient of reduction 0,65 : 8,59 tons. Adhesion at $\frac{1}{7}$ of the mean weight of 56,00 tons : 8,00 tons.

§ IX. — **Remarks on very powerful engines. Two systems available.**

263. The diversity of the conditions peculiar to each system of lines, may, up to a certain point, explain the differences in the means of working. Thus, with its heavy coal traffic, insuring heavy trains with full loads, along the whole line, and its favourable gradients which exclude, in case of working with two engines, putting one behind, the Northern of France was bound, naturally, to study the question of engines more powerful, than those with six wheels : and that question was long ago decided in the affirmative. While on other lines, on the *Méditerranée* especially, new types are rejected under conditions analogous to those in which the Northern of France applies them, and they are only accepted in cases where the gradients and traffic together render them necessary. There is a good deal of feeling in this : those who like to do something new, readily admit, and exaggerate perhaps, the advantage of very heavy trains, and the drawbacks of working with two engines.

The twelvewheeled engine of the Northern of France constitutes incontestably a progress over *Millholland's* (262); it has the advantages of the single engine : the suppression of one driver, and a somewhat more economical production of steam in a very large boiler, on condition how-

ever, of not reducing excessively, the length of the tubes; and it avoids the disadvantages of the coupling of twelve wheels, by bringing the position, in that respect, to what it is in a six wheeled engine.

But the other objections raised by an engine of very great power, fully subsist, that is to say: 1. frequently standing idle, the chances of damage which causes standing idle, increasing with the number of parts; 2. the increase, with equal traffic, of the capital sunk in the engines, by the coming into the shops, of an engine, which renders twice the capital idle, that the case would be with an engine half as powerful; 3. the necessity of special arrangements, such as turn-tables, sheds, etc.; 4. running more frequently with an incomplete, and consequently less economical load.

Let us add here, that the much greater length of the trains, the consequence of the great power of the engines on lines with flat gradients, raises a special objection, if the line is tortuous. It is stated, effectively, that the additional resistance due to a curve of given radius, referred to the unit of weight, increases with the length of the train. According to an engineer, who, on the line from *Vienna* to *Trieste*, was long in a position to fully observe these facts, numerous and sharp curves constitute a grave objection against long trains, and consequently against very powerful engines :

" The absorption of tractive force in curves," he says (*), " an absorption which resolves itself into a loss of fuel, and a greater wear and tear of way and stock, increases in a considerable proportion with the length of the train. Thus if the expenditure of fuel with a train of fifteen waggons in the curves of the Semring line, is represented by 1, the expenditure of an engine having to draw thirty waggons, will be more than double.

" The experiments we have recently made, and are in a position to make daily, leave no doubt as to this point."

We shall return, however, to this point in treating of the resistance of trains.

" It is well known also," adds the same engineer, " what it costs to keep up and handle heavy and complicated engines; we have experimented thereon, and we cannot forget the fact that the original engines of the Semring, involved an expense of 2 shil. per train mile for maintenance only."

But it was a question in that case of engines on *Engerth's* system, and it

(*) *Note sur l'exploitation du Semring de* 1860 *à* 1863, par M. *Desgranges*, p. 8, *Paris*, 1864.

is only fair to state that engines may be very heavy and very powerful, more so indeed than these alluded to, without presenting by a long way, the same disadvantages.

Altogether, the eightwheeled engine has now-a-days become a necessity, as much on account of gradients, as, but more rarely, on account of the traffic on lines with easy gradients. Perhaps one day, engines of 10 and 12 wheels will also become necessary in their turn; but at present, these types may be considered premature.

" We admire big engines," says M. *Jacqmin* (*), traffic manager of the Eastern of France, " but for the practical fact of working railways, we give the preference to engines of moderate dimensions."

Working with two engines is very differently appreciated. On some lines, the Western of France for example, it is applied without hesitation, even to trains of high speed; on others, it is adopted unwillingly even for goods trains, and of course objections are sought against it.

If one point seems evident, it is that if one engine draws 1, two identical engines ought to draw 2. They ought even to draw a little more, the resistance of the air acting more especially, in general, on the front of the train, and in that case affecting the double train less than two single ones. Stiff and numerous curves, the influence of which we pointed out just now, seem to be the only thing likely to modify this result unfavourably to the two engines working together.

However, their very considerable inferiority is ordinarily admitted and indeed set down as a practical fact beyond all contradiction, and that independently of the special action of curves.

We read in a circular order (December 1865) of the locomotive department of the Eastern of France :

"Two engines coupled to one train, while allowing an increase of the load corresponding to one engine, are far from drawing the loads which they would draw, running separately."

" Running supplementary trains is then the most advantageous step as regards working, and that which ought to be adopted, whenever the regular trains are not sufficient to clear the line."

" Double traction should then only be made use of in the exceptional cases which may arise, either from want of sufficient load for a supplementary train, or in case of

(*) *Des machines à vapeur*, t. 1er, p. 536, *Garnier* frères, *Paris*.

urgency on single lines, the formalities to be goas through for putting on supplementary trains not always permitting the use of these trains on single lines. "

An other circular order (No 80) fixes for the load for two engines to one train, the sum of the minimum loads of the two engines, minus five units (a unit is 5 tons). Moreover, in no case ought the number of vehicles, empty or loaded, to exceed once and a half the minimum number indicated for the heaviest load of the two engines, this number being even liable to reduction, if the running foreman is afraid of the couplings.

This attention to the couplings is easy to comprehend. The necessity of taking care of them, may lead to an incomplete utilisation of the power available for drawing with two engines at the head of the train; but from the purely mechanical point of view, the relative inferiority of this power is not real. What is true is that its complete utilisation assumes a perfect understanding between the two drivers, and consequently on the part of both, more constant attention. Perhaps too much is thought of this in regulating the loads, and a reduction too easily laid down as necessary, which is not in the nature of things.

264. *Joint engines of the Giovi incline.* — The drawbacks of very powerful engines with a great number of coupled wheels, and the extra expense of working with two engines have been tried to be got rid of, by constituting a sort of simple motor, with two engines coupled end to end, driven by one engineman, and carrying, necessarily, their fuel and water, for want of a tender, in tanks placed side-ways, or on the boilers themselves. M. *E. Mayer* exhibited in 1855 one of these binary engines built for the *Victor Emmanuel* line. This type has worked, and still works on the *Giovi* incline.

The first *Giovi* engines, with four wheels, had their two end cross beams fastened together, besides having tenons on one of them, entering into corresponding cavities in the other, and tightened by pressure screws. The object of this supplementary fastening was : 1. to overcome the tendency to gallop arising from the short wheel base, and overhanging position of the fire-box; 2. by perfect solidity of connection, to reduce the disturbances due to the parts with relative movement, the effects of which cannot be added together for two independent engines, excepting by a purely fortuitous coincidence; 3. to provide against the consequence of the breaking of an axle, either in front, or behind. But by this rigid connection was lost one of the advantages of the double nature of the motor, that is to say its flexibility vertically, a flexibility which allows it to follow the ine-

qualities of the line and the changes of gradient. Fastening the engines together had the inevitable effect of bringing, sometimes on one, sometimes on the other of the two intermediate axles, very considerable extra loads, which was proved by the very rapid wear of the tyres. This addition was therefore soon given up.

It had been equally applied to the engines of the *Victor Emmanuel* line; but in this case the tenons were tightened by vertical spring buffers. The drawback was reduced, but it was much better to suppress it altogether, and so give up a mode of connection for which there were really no grounds.

CHAPTER IV.

INDETERMINATION OF THE STATITICAL DISTRIBUTION OF THE LOAD BETWEEN THREE OR MORE AXLES.

265. *Limits between which the statical load of each axle may vary.* — With two axles, the distribution is invariable; with three or more axles, it can vary at will, between limits which depend on the position of the centre of gravity relatively to the axles. This indetermination may be taken advantage of, to fulfil, more or less completely, certain conditions, for example: 1. As has sometimes been done, to increase the adherent weight during bad weather, and to diminish it so as not to strain the line and the tyres uselessly, during the period for which the coefficient f is generally higher; 2. to establish a given ratio between the loads of two or more pairs of wheels, especially equality, if possible.

The distribution of the weight suspended between three axles, indeterminate in the hypothesis of the absolute invariability of the supports, depends in fact on their relative compressibility; and as they are loaded by the intermedium of springs, it is by tightening more or less these latter by means of their screw-hangers, that the distribution is made to vary between limits easily assignable.

P being the weight suspended, d the distance from the vertical of its centre of gravity to the intermediate axle B, l, l', the distance between the centres, there are only, between these given quantities and the reactions p, p', p'', of the journals, the two relations (Pl. XX, *fig.* 6).

$$p + p' + p'' = \mathrm{P} \quad \ldots\ldots\ldots\ldots \quad (a)$$
$$pl = p''l' + \mathrm{P}d \quad \ldots\ldots\ldots\ldots \quad (b)$$

B being the centre of moments.

One of the loads p, p', p'', may be given, whichever may be desired, but they must all three be positive.

If p' is given, we have:

$$p = \frac{\mathrm{P}(l'+d) - p'l'}{l+l'} \quad \ldots\ldots\ldots\ldots \quad (a')$$
$$p'' = \frac{\mathrm{P}(l-d) - p'l}{l+l'} \quad \ldots\ldots\ldots\ldots \quad (b')$$

a value which is deduced from the preceding, by substituting l for l', and *vice versâ*, and d for $-d$.

The condition that p and p'' be positive, gives :

$$p' \leqq \mathrm{P}\,\frac{l'+d}{l'},\ p' \leqq \mathrm{P}\,\frac{l-d}{l},$$

p' ought then to be at most equal to the smallest of these two values, which is evidently the second; the limits are then:

1. For p' : o and $\mathrm{P}\,\dfrac{l-d}{l}$;

2. p is a minimum, according to its value (a') for p' maximum, that is to say for $p' = \mathrm{P}\,\dfrac{l-d}{l}$, whence p minimum $= \dfrac{\mathrm{P}\,d}{l}$;

And p is maximum for p' minimum, that is to say zero, whence p maximum $= \mathrm{P}\,\left(\dfrac{l'+d}{l+l'}\right)$;

3. p'' is a minimum, according to its value (b') for p' maximum, whence p'' minimum $= o$.

p'' is maximum for p' minimum, that is to say zero, whence p'' maximum $= \mathrm{P}\left(\dfrac{l-d}{l+l'}\right)$.

The load upon the rails may then vary for each axle, between these respective limits, increased for each pair of wheels by the weight thereof; and the load on one of these axles being fixed, necessarily between its respective limits, those of the two others follow.

The expression (b) giving : $d = \dfrac{pl - p''l'}{\mathrm{P}}$, it may be said under an other form, that the variations of the loads are subject to the condition, that the function $pl - p''l'$ be constant.

This is besides evident. If setting out with a given distribution, it be desired to diminish p' for example, a certain fraction q of that load must be conceived to be taken to be spread over the two end axles. p will be then increased by $q\dfrac{l'}{l+l'}$, and p'' by $q\dfrac{l}{l+l'}$. These two forces having, relatively to B, the same moment: $q\dfrac{ll'}{l+l'}$, the total moment does not change.

266. *Position of the centre of gravity.* — There was a great dissertation at one time as to the most suitable position for the centre of gravity of the

suspended weight. After the accident of the 8th of May 1842, some builders, and particularly *Stephenson*, made a point of putting this a little behind the intermediate axle, in order that the engine might be sure not to overturn in the case of the leading axle breaking. But safety is in no way compromised by the centre of gravity being a little in front of the axle (that is to say by the relation $p\,l > p''l$); and, indeed, this position is the most frequent.

In consequence of the breakage of two leading axles of passenger-engines, accidents, which however, were attended by no ill effects, the locomotive department of the *Méditerranée* undertook, at my request, to verify the position of the centre of gravity of the suspended weight in its different types of passenger-engines. This verification comprised evidently: 1. the weighing on the table, of the load on the rails of each pair of wheels, in the normal state of the boiler as regards filling with water; 2. the weighing of the three pairs of wheels themselves, the weights of which deducted respectively from the loads on the rails gave the suspended weights p, p', p'', and there was:

$$d = \frac{pl - p''l'}{p + p' + p''}.$$

The work was interrupted by the sad occurrences of 1870-1871. The following table gives the results of 26 series including 443 engines with four wheels coupled, 330 of which are coupled behind, and 130 coupled in front.

ENGINES.		FRONT AXLE.			MIDDLE AXLE	HIND AXLE.					
Quantities.	Nos	p	l	pl	p'	p''	l'	$p''l'$	$pl-p''l'$	$p+p'+p''=\mathrm{P}$	$d=\frac{pl-p''l'}{\mathrm{P}}$
1. ENGINES WITH HIND WHEELS COUPLED.											
Express. (Outside cylinders.)											
		tons.	feet.		tons.	tons.	feet.			tons.	feet.
50	201 — 250	7,80	6,23	48,62	9,18	9,05	6,89	62,34	— 12,72	26,03	— 0,52
Ordinary. (Outside cylinders).											
45	101 — 145	7,37	5,90	43,57	7,25	7,20	6,32	45,73	— 2,16	21,83	— 0,10
15	146 — 160	7,12	6,82	48,65	8,31	8,38	6,32	53,18	— 4,53	23,82	— 0,20
76	522 — 597	6,53	5,07	33,14	7,92	8,16	5,77	47,15	— 14,01	22,62	— 0,62
20	599 — 618	6,21	5,07	31,53	8,31	8,55	5,77	49,38	— 17,85	23,08	— 0,79
12	619 — 630	6,53	5,07	33,15	7,80	7,81	5,77	45,11	— 11,94	22,15	— 0,56
15	631 — 645	7,54	5,07	38,25	7,51	7,67	5,77	44,36	— 6,11	22,73	— 0,26
16	701 — 716	8,03	5,80	46,65	8,84	8,93	5,71	50,98	— 4,33	25,80	— 0,16
10	717 — 726	7,07	5,25	37,14	8,75	8,70	5,74	49,97	— 12,83	24,53	— 0,52
2	737 — 738	8,97	5,80	52,13	8,25	8,34	5,71	47,61	+ 4,52	25,57	+ 0,16
30	751 — 780	6,28	5,80	36,48	8,16	8,18	5,71	46,72	— 10,24	22,63	— 0,46
20	781 — 800	5,94	5,80	34,55	8,33	8,36	5,71	47,73	— 13,18	22,64	— 0,59
19	801 — 819	6,10	5,80	35,43	9,03	9,06	5,71	51,74	— 16,31	24,20	— 0,66
2. ENGINES WITH FRONT WHEELS COUPLED.											
15	286 — 300	8,39	7,05	59,06	7,80	3,14	7,38	23,22	+ 35,84	19,34	+ 1,84
3	301 — 303	7,90	7,27	57,45	7,56	3,06	6,61	20,24	+ 37,21	18,52	+ 2,00
9	304 — 312	7,50	7,27	54,53	7,16	3,16	6,61	20,97	+ 34,63	17,82	+ 1,87
5	313 — 317	8,41	7,05	59,32	7,82	3,28	7,38	24,24	+ 35,08	19,52	+ 1,77
2	318 — 319	8,24	7,05	58,13	7,65	5,17	8,04	41,64	+ 16,49	21,07	+ 0,75
13	320 — 332	8,41	7,05	59,32	7,82	3,28	7,38	24,24	+ 35,08	19,52	+ 1,77
5	333 — 337	8,15	7,05	57,48	7,56	3,11	7,38	22,98	+ 34,50	18,83	+ 1,80
17	351 — 367	8,27	7,27	60,14	7,73	3,75	6,61	18,18	+ 41,96	18,75	+ 2,23
11	368 — 378	8,45	7,27	61,45	8,23	2,66	6,61	17,59	+ 43,86	19,34	+ 2,26
5	379 — 383	8,04	7,05	56,76	7,77	3,40	6,85	23,37	+ 33,39	19,22	+ 1,71
7	451 — 457	7,36	7,27	53,51	7,09	3,14	6,61	40,77	+ 12,84	17,59	+ 1,84
11	458 — 468	8,20	7,05	57,91	7,85	2,73	6,85	18,78	+ 39,13	18,80	+ 2,17
10	506 — 515	8,71	5,90	51,51	8,06	2,56	6,23	15,98	+ 35,53	19,34	+ 1,80
443											

We see: 1st That the engines with hind wheels coupled have the centre of gravity of the suspended weight behind the driving-wheel; there is no exception, but for the two engines in the series, 737-738; 2nd That the distance goes down to 0 ft, 09, and does not exceed 0 ft, 79; 3rd That engines coupled in front have on the contrary, the centre of gravity of the suspended weight in front of the driving axle, and the distance only goes down exceptionally to 0 ft, 75, and reaches 2 ft, 26.

The two engines, the axles of which broke, belonged to the first group; they had not, then, independently of their connections, any tendency to turn over. But the conditions are, it will be seen, very different for the major part of the engines of the second group, which are coupled in front.

267. The weights of the wheels, indispensable for determining the exact position of the centre of gravity of the suspended weight, are scarcely ever given in the descriptions of engines, which give only the normal loads on the rails. But without knowing the weights of the pairs of wheels, it can often be judged on which side of the intermediate axle, the point in question is placed. From the loads on the rails, and the distances between centres, the distance D is deduced of the *general* centre of gravity to the middle axle; and if there is a certainty that the centre of gravity of the whole of the wheels is found on the same side of the axle and nearer to it than the general centre of gravity, it is evident that the centre of the suspended weight is on the same side, but farther from the axle, the general centre being necessarily comprised between the two partial centres.

Example:

1. English engine uncoupled (Nos 51-66), driving axle in the middle, and with inside cylindres, of the *Méditerranée.* Loads on the rails:

$q_1 = 9\,\text{tns},20$; $q' = 12,00$; $q'' = 5\,\text{tns},25$; distances between the centres: $l = l' = 7\,\text{ft},50$.

$$D = \frac{(9,20 - 5,25)\,7\,\text{ft},50}{26,45} = +\,1\,\text{ft},12.$$

The two extreme pairs of wheels having the same diameter, and consequently the same weight, and the same distance between centres, the special centre of gravity of the wheels, falls on the middle axle; the centre of the suspended weight is then in front of the driving axle, and at a distance greater than 1 ft, 12.

2. Engines from the *Nîmes* workshops (inside cylinders).

$$q = 10\,\text{tns},10;\quad q' = 12,00;\quad q'' = 5\,\text{tons},43;\quad l = l' = 7\,\text{ft},49$$

D = 1 ft, 25; same conclusion as for the preceding ones.

Mr *D. K. Clark* is of opinion that the general centre of gravity ought, like the centre of the suspended weight, to be a little in front of the axis of the middle axle, in order, he says, that on a curve, the centrifugal force may be destroyed by the reactions of the flanges of the outside wheels of the front and middle (*). This opinion based without doubt on the greater load, in engines with free wheels, on the front axle than on the hind axle, seems to be little grounded; the distance from the general centre of gravity to the intermediate axle is not great enough for its direction to have a notable influence on the conditions of pivoting by which the engine places itself at each instant, along the curve. It is besides by raising up the outside rails, and not by their reactions on the flanges that the centrifugal force is equilibrated.

The Eastern of France had several small engines of the *Stephenson's* type, with a heating surface of 706 square feet, weighing full 22 tns, 05, thus distributed: in front 6 tns, 60; middle (driving axle) 9 tns, 85; hind 5 tns, 60. In this state the centre of gravity was a little in front (0 ft, 39) of the driving axle. The instability of these engines was extreme, as soon as the speed was more than 30 miles an hour; several trains ran off the line between *Strasburg* and *Bâle*, worked by them, so that they were obliged to be given up, and were replaced by *Crampton's* engines. Almost all of them, by degrees as they came into the shops to have their boilers repaired, were altered into engines with four wheels coupled. Pl. LXXIX, *fig.* 3 shows the two types placed together; we see that the whole is limited to a slight lengthening of the barrel.

The heating surface has become 778 square feet, and the weight 25 tons distributed thus: in front 8 tons; middle (driving axle) 8 tns, 60; hind 8 tns, 4. The centre of gravity has passed from in front to behind, to 0 ft, 30. The engine has however gained greatly in stability, although the smallness of its front wheels always renders it little suitable for high speeds. The improvement which is produced, entirely irrespective of the displacement of the centre of gravity, is due to the greater load of the end axles; as to the ratio between the length of base and the length of the engine, it has not varied sensibly.

The general centre of gravity is ordinarily a little above the upper edge of the longitudinals, that is to say, in passenger engines, at about 4 ft, 00 above the rail.

(*) *Railway machinery*, p. 188.

268. *Engines with four axles.* — It is as easy to assign the limits of the loads for engines with four axles.

Having (Pl. XX, *fig.* 8) the two relations:

$$p + p' + p'' + p''' = \mathrm{P}; \quad p''l + \mathrm{P}d = p''l' + p'''(l + l''),$$

two of the four reactions may be assumed, under the conditions that they are all positive. But not to dwell on so simple a subject, it is sufficient to remark, the centre of gravity being supposed comprised between the two intermediate axles B, C, that each of the four reactions has zero for minimum, each of the supports being able to be completely withdrawn, without P ceasing to be comprised between two points of support. As to the maximum of each reaction, it is evidently obtained in decomposing P between the support which is considered, and the farthest of the other supports placed on the opposite side relatively to P. We have thus:

	MINIMUM.	MAXIMUM.	SUPPORT LOADED.
A	0	$\mathrm{P}\,\dfrac{l' + l'' - d}{l + l' + l''}$	A and D
B	0	$\mathrm{P}\,\dfrac{l' + l'' - d}{l' + l''}$	B and D
C	0	$\mathrm{P}\,\dfrac{l + d}{l + l'}$	C and A
D	0	$\mathrm{P}\,\dfrac{l + d}{l + l' + l''}$	D and A

269. *Equality of the loads on two contiguous axles.* — The indetermination of the loads or rather the faculty of making them vary between the indicated limits allows them to be subjected to certain conditions.

Thus for engines with three axles, the ratio of two of the loads may be assumed.

When it is a question of coupled wheels, it is desirable that this ratio should be unity. The equality of the loads gets rid of in effect, one of the causes of the inequality of the diameters, that is to say, the differences of wear of the tyres.

x being the load common to two contiguous axles, we have (Pl. XX, *fig.* 9) the moments being at B :

$$lx = l'(\mathrm{P} - 2x) + \mathrm{P}d, \quad \text{whence} \quad x = \mathrm{P}\,\frac{l' + d}{l + 2l'},$$

a value comprised between the respective limits of the loads on these two axles.

The load on the third is: $P-2x=P\frac{l-2d}{l+2l'}$, comprised equally between the limits affecting it.

270. *Equality of the loads on the two extreme axles.* — For the equality of the loads on the two extreme axles, we should have:

$$lx=l'x+Pd,\quad \text{whence}\quad x=\frac{Pd}{l-l'},$$

a value which ought to be comprised between the limits

$$\frac{Pd}{l}\quad\text{and}\quad P\frac{l'+d}{l+l'}\quad\text{of the load on A,}$$

and the limits:

$$o\quad\text{and}\quad P\frac{l-d}{l+l'}\quad\text{of the load on C.}$$

1. The condition $\frac{Pd}{l-l'}>o$ comes to $l>l'$.
2. If it is satisfied, the condition $\frac{Pd}{l-l'}>\frac{Pd}{l}$ is so also.
3. The condition $P\frac{d}{l-l'}<P\frac{l'+d}{l+l'}$, comes to $d<\frac{l-l'}{2}$.
4. The condition $P\frac{d}{l-l'}<P\frac{l-d}{l+l'}$ comes also to $d<\frac{l-l'}{2}$.
5. We must, then, have $l>l', d<\frac{l-l'}{2}$.

Equality, always possible for two contiguous axles, is not always so for the end axles.

We see at once why; the suspended weight P must, in effect, be for equality, decomposable between the intermediate axle B and the middle M of the interval $l+l'$ of the end axles. This point must then fall, relatively to P, on the opposite side to B, that is to say, that we have:

$$CM=\frac{1}{2}\left(l+l'\right)>l'+d,\quad\text{and}$$
$$AM=\frac{1}{2}\left(l+l'\right)<l-d,$$

conditions which both come to:

$$d<\frac{1}{2}\left(l-l'\right).$$

Equality is then possible. The load of B is: $P\frac{MG}{MG+d}$ or, because of

$$MG=l-d-\frac{1}{2}\left(l+l'\right)=\frac{1}{2}\left(l-l'\right)-d,$$
$$P\left(1-\frac{2d}{l-l'}\right);$$

and that of M is: $\frac{2Pd}{l-l'}$ or on each of the end axles: $P\frac{d}{l-l'}$. This case is

moreover of no practical interest. When there are only two coupled axles they are always contiguous.

271. *Equality of the loads on the three axles.* — Let us return to the equality of the loads in this case. The load of the third axle $P\frac{l-2d}{l+2l'}$, is equal to the load $P\frac{l'+d}{l+2l'}$, on each of the two others, if $d=\frac{1}{3}(l'-l)$, a condition which ought to be approximated to, in engines with six wheels coupled, and which it is in general easy enough to fulfil nearly. The coupled wheels being of the same diameter and consequently of the same weight, the equality of the loads on the rails, which is the object, corresponds to the equality of the suspended loads, unless for the driving axle, subjected to the vertical efforts applied directly to it by the driving rods; they can be taken into account by a certain reduction of the suspended weight.

For four axles, the condition of equality is:

$$d=\frac{1}{4}\left(l'+l''-l\right).$$

The partial equality or total (if it is possible), may after having been realised by the adjustment of the springs, disappear more or less rapidly in consequence of the unequal alteration of their elasticity. It is easy to remove this cause of disturbance from the equality, and in general to render the statical distribution adopted invariable, by connecting together the springs that load the different axles; a point to which we shall presently return.

But there is another cause of disturbance, in which this expedient is of no use; it is the expenditure of the engine in fuel and water, especially the latter. If the position of the centre of gravity varies with this expenditure, and such is ordinarily the case, the condition under which the equality of all loads is possible is only fulfilled for a determined amount of water in the boiler. If it is modified, if the position corresponding of the centre of gravity is considerably affected, and if, lastly in consequence of the solid manner in which the springs are fastened together, their reactions, being to each other constant ratio, can only balance the suspended weight when the centre of gravity is at its initial position; as soon as it is displaced this equilibrium is impossible, or at least it can only be established by the intermedium of the friction developed by deformation, or disarrangement of the pieces of the system, whatever that may, which transmits the load to the axles. This objection, rigorously true, has seemed serious enough to

some engineers to make them reject those connections which insure the equality of the loads in the given state for which it is possible. This is going too far. The distances from the position of the centre of gravity under the influences of the causes indicated, are in general too slight for the primitive distribution to be notably disturbed. The solid connection together of the bearing springs has besides advantages of an other nature and of greater import, which will be pointed out farther on. (291 and follow.)

The form of the fire-box going very low down below the body of the boiler was long an obstacle against a proper distribution of the weight between the axles, as the hind axle could only be placed either in front of the fire-box, or behind it; now-a-days the fire-boxes being much shallower or the grate being inclined, consequences of the more general substitution of coal for coke, which at first was used only in locomotives, allow the hind axle to be placed under the fire box, provided that the diameter of the wheels be not too great. It is thus easy to reconcile every thing; stability of the engine, reduction of the overhanging of the fire-box, moderate distances between centres, good distribution of the weight. This arrangement was carried out as far back as 1857, by Mr *Cudworth* in the alteration of the engines of the *South-Eastern*, and before 1860, by *Baldwin* the American builder.

CHAPTER V.

CAUSES WHICH PRODUCE A VARIATION DURING RUNNING, OF THE DISTRIBUTION OF THE WEIGHT AMONG THE AXLES.

The variations of the distribution of the weight affect not only the adhesion in engines with the weight partially adherent, the preservation of the permanent way and the tyres, but also the stability; it is of importance to measure them, and to confine them within such limits as may not compromise safety.

The causes inherent to the engine itself, to the conditions of its work, and which can be calculated, are:

1. The pressure of the steam on the pistons;
2. The inclination of the cylinders;
3. The consumption of fuel and water which the engine carries itself, a cause already pointed out (271);
4. The gradient of the line;
5. The application of the effort of traction at a level more or less different to that of the driving axle, or axles;
6. The inertia of the parts animated with relative velocities.

§ I. — Effects of the pressure of the steam in the cylinder, and the effect of the inclination thereof.

272. *Fourwheeled engines.* — Let us take a fourwheeled engine, with distance between centres d, and with inclined cylinders. Let (Pl. XX, *fig.* 4 i be their angle with the horizon; r the crank; b the connecting rod; δ and δ', the horizontal projections of the distances of the front axle, to the centres of the top and bottom of the cylinders; π the effective pressure on the pistons; α and β the simultaneous angles of the connecting rod and crank with the axis of the cylinder; let us consider the engine in forward gear.

Righl side: I. *Forward stroke.* I. The tension π of the piston-rod gives: along the connecting-rod $\frac{\pi}{\cos\alpha}$; normally to the upper guide $\pi \operatorname{tang}\alpha$.

II. The tension $\frac{\pi}{\cos\alpha}$ of the connecting rod gives on the driving axle:

horizontally, $\frac{\pi}{\cos\alpha}\cos(\alpha - i)$, directed from left to right; vertically,

$$\frac{\pi}{\cos\alpha}\sin\left(\alpha - i\right).$$

III. The force $\pi \operatorname{tang}\alpha$, applied normally to the guide, from below upwards, gives: vertically, $\pi \operatorname{tang}\alpha \cos i$; and horizontally, from left to right, $\pi \operatorname{tang}\alpha \sin i$.

IV. The force π, applied to the bottom AB of the cylinder gives: vertically, from above downwards, $\pi \sin i$; and horizontally from right to left, $\pi \cos i$.

We have thus for the sum of the horizontal components, with regard to their respective directions:

$$\frac{\pi}{\cos\alpha}\cos\left(\alpha - i\right) - \pi \operatorname{tang}\alpha \sin i - \pi \cos i.$$

that is to say o, which is evident, these internal forces neutralising each other by the intermedium of the frame.

The admission of the steam into the cylinder which we are considering adds to the statical charge on the driving axle:

I. The force $\frac{\pi}{\cos\alpha}\sin(\alpha - i)$;

II. The component of the force $-\pi \operatorname{tang}\alpha \cos i$, applied at the guide, and decomposed between the two axles, or $-\operatorname{tang}\alpha \cos i\left(1 - \frac{\lambda}{d}\right)$, λ being the projection of the distance from the head of the piston rod to the driving axle; or on account of $\lambda = (b\cos\alpha - r\cos\beta)\cos i$,

$$-\pi \operatorname{tang}\alpha \cos i\left(1 - \frac{b\cos\alpha - r\cos\beta}{d}\cos i\right);$$

III. The component of the force $+\pi \sin i$ applied at the bottom AB of the cylinder, and which decomposed between the two axles, gives on the driving axle: $-\pi \sin i\frac{\delta}{d}$.

The load brought from the leading axle onto the driving axle, by the simple fact of opening the regulator, is then:

$$\frac{\pi}{\cos\alpha}\sin(\alpha - i) - \pi \operatorname{tang}\alpha \cos i\left(1 - \frac{b\cos\alpha - r\cos\beta}{d}\cos i\right) - \pi \sin i\frac{\delta}{d}$$
$$= -\pi \sin i\left(1 + \frac{\delta}{d}\right) + \frac{\pi \operatorname{tang}\alpha \cos^2 i}{d}(b\cos\alpha - r\cos\beta);$$

eliminating α by the relative $\sin\alpha = \frac{r}{b}\sin\beta$, whence

$$\cos\alpha = \frac{1}{b}\sqrt{b^2 - r^2\sin^2\beta}, \quad \operatorname{tang}\alpha = \frac{r\sin\beta}{\sqrt{b^2 - r^2\sin^2\beta}}.$$

$$\text{(A)} \qquad T = -\pi \sin i\left(1 - \frac{\delta}{d}\right) + \frac{\pi r \sin\beta \cos^2 i}{d}\left(1 - \frac{r\cos\beta}{\sqrt{b^2 - r^2\sin^2\beta}}\right);$$

a value which applies to the forward stroke, that is to say, between $\beta = 0$ and $\beta = 180°$.

2. *Back stroke.* In the same way we find for the back stroke, β being always reckoned from the origin of the forward stroke, and thus comprised between $\beta = 180°$ and $\beta = 360°$:

$$\text{(B)} \qquad T' = \pi \sin i\left(1 - \frac{\delta}{d}\right) - \frac{\pi r \sin\beta \cos^2 i}{d}\left(1 - \frac{r \cos\beta}{\sqrt{b^2 - r^2 \sin^2\beta}}\right).$$

a value immediately deduced from the preceding, by replacing π by $-\pi$, and δ by δ'.

Left side. For the other piston, bringing equally the angular positions of its crank to the initial position of the crank of the right hand piston, we shall evidently obtain the simultaneous values of the strains on that side by substituting, in (A) and (B), β by $\beta + 270°$, which gives:

Forward stroke:

$$\text{(C)}\ T_1 = -\pi \sin i\left(1 - \frac{\delta}{d}\right) - \frac{\pi r \cos\beta \cos^2 i}{d}\left(1 - \frac{r \sin\beta}{\sqrt{b^2 - r^2 \cos^2\beta}}\right).$$

Back stroke.

$$\text{(D)}\ T'_1 = \pi \sin i\left(1 - \frac{\delta}{d}\right) + \frac{\pi r \cos\beta \cos^2 i}{d}\left(1 - \frac{r \sin\beta}{\sqrt{b^2 - r^2 \cos^2\beta}}\right).$$

It is then easy to have the expression of the total increase of load on the driving axle, corresponding to any angle β, through which that axle may have turned.

First quarter of a revolution: from $\beta = 0$ to $\beta = 90°$.

The right hand piston makes its first forward half-stroke, and the left its second back-half stroke. (A) and (D) must therefore be added together, which gives:

$$\theta = \frac{\pi \sin i}{d}(\delta - \delta') + \frac{\pi r \cos^2 i}{d}\left(\sin\beta + \cos\beta - \frac{r \cos\beta \sin\beta}{\sqrt{b^2 - r^2 \sin^2\beta}} - \frac{r \sin\beta \cos\beta}{\sqrt{b^2 - r^2 \cos^2\beta}}\right).$$

Second quarter of a revolution: $\beta = 90°$ to $\beta = 180°$.

The right hand piston makes its second forward half stroke, and the left hand one its first half stroke in the same direction.

(A) and (C) must therefore be added, whence:

$$\theta_1 = -2\pi \sin i\left(1 - \frac{\delta}{d}\right) + \frac{\pi r \cos^2 i}{d}\left(\sin\beta - \cos\beta - \frac{r \sin\beta \cos\beta}{\sqrt{b^2 - r^2 \sin^2\beta}} + \frac{r \sin\beta \cos\beta}{\sqrt{b^2 - r^2 \cos^2\beta}}\right).$$

Third quarter of a revolution: $\beta = 180°$ to $\beta = 270°$.

The right hand piston makes its first half return stroke, and the left

hand one, its second forward half-stroke. (B) and (C) must then be added, whence:

$$\theta_2 = \frac{\pi \sin i}{d}(\delta - \delta') - \frac{\pi r \cos^2 i}{d}\left(\sin\beta + \cos\beta - \frac{r \sin\beta \cos\beta}{\sqrt{b^2 - r^2 \sin^2\beta}} - \frac{r \sin\beta \cos\beta}{\sqrt{b^2 - r^2 \cos^2\beta}}\right).$$

Fourth quarter of a revolution: $\beta = 270°$ to $\beta = 360°$.

The two pistons are on their return stroke, the right hand one doing the second half, and the left hand one the first half thereof; it is therefore the expressions (B) and (D) which have to be added, which gives:

$$\theta_3 = 2\pi \sin i\left(1 - \frac{\delta'}{d}\right) + \frac{\pi r \cos^2 i}{d}\left(\cos\beta - \sin\beta - \frac{r \sin\beta \cos\beta}{\sqrt{b^2 - r^2 \cos^2\beta}} + \frac{r \sin\beta \cos\beta}{\sqrt{b^2 - r^2 \sin^2\beta}}\right).$$

If the cylinders are horizontal, and if moreover we neglect $r^2 \sin^2\beta$ and $r^2 \cos^2\beta$ against b^2, these values become reduced to:

$$\theta = \frac{\pi r}{d}\left(\sin\beta + \cos\beta - \frac{2r}{b}\sin\beta\cos\beta\right),$$

$$\theta_1 = \frac{\pi r}{d}(\sin\beta - \cos\beta).$$

$$\theta_2 = -\frac{\pi r}{d}\left(\sin\beta + \cos\beta - \frac{2r}{b}\sin\beta\cos\beta\right).$$

$$\theta_3 = -\frac{\pi r}{d}(\sin\beta - \cos\beta).$$

The condition of the limits of θ is satisfied by $\tan g\,\beta = 1$, or $\beta = 45°$; the second derivative: $-\sin\beta - \cos\beta + \frac{4r}{b}\sin\beta\cos\beta$ becomes for this value of β: $-\sqrt{2} + \frac{2r}{b}$. Now b is always greater than $r\sqrt{2}$; the second function is then, negative.

The maxima correspond in the same way, respectively:

for θ_1,	to	$\tan g\,\beta = -1$	or	$\beta = 135°$,
θ_2,		$\tan g\,\beta = 1$	or	$\beta = 225°$,
θ_3,		$\tan g\,\beta = -1$	or	$\beta = 315°$.

Values which are suitable, seeing that they are inferior to the respective limits: 90°, 180°, 270°, 360°, of β.

The maxima are:

$$\theta = \frac{\pi r}{d}\left(\sqrt{2} - \frac{r}{b}\right); \quad \theta_1 = \frac{\pi r}{d}\sqrt{2}; \quad \theta_2 = \frac{\pi r}{d}\left(\sqrt{2} - \frac{r}{b}\right); \quad \theta_3 = \frac{\pi r}{d}\sqrt{2}.$$

The smallest values correspond to the limits of each quadrant: $\beta = 90°$, 180°, 270°, 360° and have for common value: $\frac{\pi r}{d}$.

P being the weight of the engine, k the distance from the vertical through the general centre of gravity, to the axis of the driving axle, the load on the latter varies between

$$\mathrm{P}\frac{d-k}{d} \text{ (regulator closed), and } \frac{1}{d}\left\{\mathrm{P}(d-k)+\pi r\sqrt{2}\right\} \text{ (regulator open).}$$

In engines with six wheels, the decomposition between the three axles, of the forces applied at the guides, and at the ends of the cylinders, is indeterminate as is that of the suspended weight, and only the limits can in this case be assigned between which the load on each axle is comprised, according to the adjustment of the springs (265).

In what precedes, we have not taken into account the inequality of the quantities of steam admitted, by the usual valve gearing, on the two sides of the piston. The mean effective pressure π is not of course quite the same for the two strokes. But the influence of this inequality on the disturbance of which we are treating is very slight.

273. *Effect of the inclination of the cylinders.* — The most serious effect of the inclination of cylinders is evident. During the forward stroke the bottom AB is submitted like the piston to normal pressure π, the horizontal component of which, $\pi \cos i$, is destroyed by the connections of the system, while the vertical component, $\pi \sin i$ directed from above downwards is added almost wholly to the load of the front spring of the same side. During the return stroke, it is the reverse; the component, $\pi \sin i$ directed from below upwards, has to be deducted from the load. To these variations of load correspond variations in the deflections of the springs, and consequently an oscillatory or *galloping* movement of the boiler. But on account of the rectangular position of the cranks, the increase and reduction of the load on one side correspond periodically to a reduction and increase of the other side; so that the boiler oscillates at the same time round a horizontal transversal axis and round a longitudinal one; it takes not only a galloping but also a rolling movement. Thence extreme instability commences as soon as the inclination of the cylinders and the speed exceed certain limits; thus the considerable inclination admitted in certain engines was soon given up. It was warranted in some cases by the coupling of the front wheels and by the fact of applying the connecting rod directly to the driving wheel (261). The cylinders and so on, had then to be raised so that the crankpin of the front wheel and the head of the rod should perform their revolutions under the lower guide, in backward gear. But the instability of the engine went to an intolerable point, with-

out taking into account the difficulty of fixing the cylinders solidly to the longitudinals, and the very awkward position of the valve boxes, when they were applied laterally to the cylinders and on the inside, obstructed the orifices of the tubes in the smoke box, and were subjected to an excessive temperature. Thence arose the necessity either of placing the connecting rod away beyond the front coupling rod, putting up with the widening of the engine resulting therefrom, or to put the cylinders inside.

In that case the cylinders ought to be slightly inclined; the front axle being on the same level as the driving axle, the piston rods and their guides must of course pass either over the first axle (engine of the Western of France, Pl. XLI, *fig.* 1, and XLII, *fig.* 2) or underneath as is often done in Belgium, for example. But within these limits, the inclination has no drawback, any more than in certain engines with front wheels uncoupled like *Buddicom's*, where the outside cylinder is raised a little, as well as the front of the outside longitudinals to leave the place free for the bearing spring above the axle box.

§ II. — Variations resulting from the expenditure of fuel and water.

274. An engine consumes water and fuel; this consumption has not only the effect of diminishing the weight, it reacts also on the position of the centre of gravity and consequently on the distribution of the weight. Those engines, the fuel and water of which is carried by a tender, and such is the case with the greatest number, can during running, make good their losses, or at least partly. Thus this cause little affects the distribution of their weight; but it is not the same for tank engines, that is to say those carrying their own water and fuel. It is important in these to arrange the tanks in such a manner that the position of their centre of gravity varies little with the expenditure. This condition has been often too much neglected; the tank engines of the *Midi* of France for example, with their great water tanks concentrated towards the back have when full an excessive load on the hind axle, and with their fuel and water almost all expended, an excessive load on the front axle.

The alteration of these very badly designed engines, and of which the *Midi* had a considerable number, has naturally received great consideration from its engineers. They made a beginning by applying a separate tender to a certain number of them, replacing the unlucky tanks by an enormous amount of cast iron ballast (4 tons) placed under the frame, the excessive

overhanging of which was suitably reduced. In others, the change is more thorough; the driving axle has been brought towards the front, and this measure combined with the lengthening of the boiler, allowed the hind wheels to be placed in front of the fire box, and a good distribution of the weight to be thus obtained without having recourse to ballast; but the price of this complete remodelling is so great, that they have abstained from its further application; and it has been restricted to a few engines. The greater portion of the engines of this troublesome type remains intact, and is utilised as much as possible for shunting. These engines remain as a lesson; they prove how difficult it is sometimes to repair a fault, serious in itself, and by the scale on which it has been committed.

§ III. — Influence of gradients and of variations in speed.

275. *Gradients.* — The inclinations of the line which have so great an influence on the effort of traction necessary, modifies also, but only in proportions so to say infinitesimal, the adhesion due to a *given weight.* The adhesion due to a weight P, which is fP on a level, is on an incline (up) $\frac{1}{i}$,

$$fP\sqrt{1-\frac{1}{i^2}}.$$

Even for $\frac{1}{i}=\frac{1}{20}$ a tremendous inclination, the loss is quite inappreciable.

If then the centre of gravity kept the same position on a rising gradient as on a level, relatively to the axles, variations in the section would have quite inappreciable influence on the adhesion. This invariability is evidently not even necessary for engines in which all the wheels are coupled. But it is not the same for engines, with only partial adhesion; the latter is, according to the type of the engine, greater or smaller on a gradient than on a level. When an engine goes from a horizontal on to a rising gradient, the fire-box gets filled, with the water then accumulating at the end of the engine. The centre of gravity is displaced in the same direction, and the load of the hind wheels increases : the adhesion profiting thereby if these wheels are coupled, but losing if it is the front ones; the deflection of the hind springs increasing, on account of their greater load, increases the inclination of the boiler a little, and consequently the accumulation of water. On passing from a horizontal on to a down incline, the effects are reversed and the water accumulates forwards. This is of no consequence as regards

the ordinary action of adhesion, the effort of traction being reduced, or even *nil*. But the advantage, which belongs then to the front wheels coupled, remains from the point of view of stopping; it exists even with respect to running, when the inclination is great enough to require the constant application of a retarding force, the adhesion of the engine serving as an intermedium for its retarding force, just as for its effort of traction.

AB (Pl. XX, *fig.* 11) being the level of the water on a horizontal, CD the same level on arising gradient, A′B′ the position which the first line of level makes therewith, the volume which is displaced is SB′D or its equal SA′C; the primitive line of level is carried from A′B′ to CD, turning round S, and the amplitude of the displacement is the distance between the centres of gravity g, g' of the two masses c'; the point S is not exactly in the middle of the lines A′B′, CD, and the portions out of level A′C, B′D, are not equal, the transverse section not being uniform; it is greater behind, so that the portion out of level there is less. The distribution of the weight is then modified by a couple $\pi \times g\,g' = \pi \times \frac{2}{3} l$, π being the common weight of the equal volumes SB′D, SA′C, and l the finished length of the boiler.

This displacement of water has moreover no influence on the adhesion as long as it is considerable, that is to say on lines with steep gradients, for then the engines have all their wheels coupled; thus its most serious effect is not resulting disturbance of the distribution. This effect, or better to say this danger, which being in common cause we indicate at once, is the emergence of a part of the heating surface of the boiler. But the seriousness of this danger depends essentially on the direction of the inclination. If the engine goes from the horizontal on to a rising gradient, the ends of the upper rows of tubes may go above the surface of the water; if it goes from the horizontal, or with greater reason from a down incline on to an up one, it is the top of the fire-box which becomes exposed; a more serious accident than the first, the temperature being higher in the fire-box than at the front end of the tubes, and the burning of the roof of the fire-box being far more serious than the same accident to the tubes. A driver little acquainted with the gradients of the line, by attending only to the gauge-glass, might allow himself to be caught thus to point of passing on to a down incline, and damage his boiler seriously.

To prevent accidents of this kind as far as possible, and to show up the driver's neglect at once, a screwed plug is inserted in the top of the fire-box containing a lead core tapering out downwards. The plug projects above the upper surface of the fire-box, in such a way that the lead

comes out of the water first. No longer having the water to cool it, it melts, and the water and steam rushing into the fire-box soon put out the fire.

The driver who allows his plug to be melted is in general severely punished. The fusion of the lead plug must not be confounded with its simple expulsion by the inside pressure, which effect might be produced in consequence of the gradual loosening of the leaden plug; but it thus often really involves the driver, who is responsible for the state of his engine, and for all visible damage which he has not either repaired if within his power, or made known to his running foreman.

In engines intended for running on very steep inclines this danger is avoided by a suitable arrangement of the roof of the fire-box. With the ordinary arrangment, that is to say when the top of the fire-box is horizontal on a level, it is evidently the hind part on a down incline which is the most in danger, and which first emerges. By giving the roof an inclination backwards equal to the greatest inclination on the line, the top no longer partially emerges of; it is either not uncovered at all, or is entirely so, as on a level, when it is horizontal.

276. *Variations of speed curves.* — It is almost useless to add that the displacement of the water occurs also under the influence of the variations of speed. The water goes out of level and accumulates behind, when the engine gets up its speed and starts, and in the front, when it slackens speed and stops. But the influence is inappreciable of these displacements which are temporary, and little marked unless in the case of very sudden variations of speed.

It is the same thing with respect to another cause which does not in this case modify the longitudinal, but the transverse surface of the water, so that the corresponding disturbance consists of an inequality in the loads on the two sides of the engine: the curves. But if the centrifugal force tends to accumulate the water towards the outside of the curve, raising the rail tends (I, 200) to accumulate it on the opposite side, and altogether the effect is scarcely perceptible.

§ IV. — **Influence of the effort of traction on the train drawn.**

277. If the effort of traction t, applied parallel to the line, passed through the axis of the driving axle, it would not modify the distribution in any way. The frame of the engine would be in effect solicited by two forces directly opposed: the one, the pushing of the driving axle or axles against the guard

plates; the other, the resistance of the train drawn. The difference of these two forces is equal to the effort required for drawing the engine alone, deduction being made of that which represents the resistance of the machinery, as the effort available on the driving axle evidently does not include that which counterbalances this resistance.

Mr *D. Clark* (*) rightly opposes one of the motives sometimes brought forward in support of the lowering of the boiler, that is to say the utility of bringing the general centre of gravity as much as possible to the level of the line of traction. Lowering the boiler, we have already said (249) is useful, but not from that point of view. What would really be desirable, but is rarely possible, is that the line of traction, always parallel to the line, should pass through the point of propulsion, that is to say through the axis of the driving axle. If it is either over or under this point by the height h (Pl. XX, *fig.* 16), a couple $t \times h$ results, which tends to make the engine turn over from the front to the back in the first case, and from the back to the front in the second, and which in that case modifies the distribution of the weight.

In a fourwheeled engine, for example, with a distance between centres l, the couple $t \times h$ which tends to lift up the front diminishes the load on the front axle by $\frac{t \times h}{l}$. The front load is then, P being the total weight and d the distance from the general centre of gravity to the driving axle: $\frac{Pd - th}{l}$; and that of the driving axle: $\frac{P(l-d) + th}{l}$.

The initial distribution is thus more effected the smaller l is, but this greater variation is applied to an initial greater load also.

Practically, the line of traction placed at 3 ft, 3 from the rail is hardly ever above the point of propulsion. It is almost exactly on the same level in engines with large driving wheels, 6 ft, 6, a little higher in ordinary passenger engines, and a great deal higher in goods engines because of the smallness of their wheels.

Mr *Clark* quotes *Bury's* fourwheeled engines, which had a great tendency to rise up in front, in consequence of the great height of the line of traction above the driving axle, and several cases of running off the line have had to be put down at least partly to this cause. It was especially at starting that this tendency was manifested, the effort of traction being then at its maximum.

(*) Railway machinery, p. 187.

The same effect was produced in the six wheeled engines. The engine *Euclid* of the railway from *Edinburgh* to *Glasgow*, with four wheels coupled (hindwheels) "was known," says the same author (*) "to slip less the heavier its loads". Putting aside a certain exaggeration in the expression, the fact had reference to the height of the drawbar above the centre of the driving-wheels : 0 ft, 82. The more considerable was the effort of traction, the greater also was the load that it brought on the adherent wheels. But the distance apart (not indicated) of the axles must have been very slight for the distribution to have been so greatly modified.

The variation of distribution under the influence in question, is at the same time, much greater in low speed engines than in others, because with equality of power and weight, the effort of traction and the distance apart of the point of propulsion from the line of traction, that is to say the two factors of the disturbing couple, are so much the greater, the smaller the wheels. The influence of this couple is slight however in consequence of the great length of the wheel base. If we take for example one of the engines with eight wheels coupled, 4 ft, 26, already quoted (259), those of the Northern of France, its effort of traction calculated at 0,65 (coefficient) is 6 tns, 50 with reference to the adhesion of $\frac{1}{7}$. This effort is applied at 3 ft, 18 above the rails, and consequently at 3 ft, 18 — 2 ft, 13 = 1 ft, 05 above the line of the centres. The couple which tends to make the engine turn over from front to back is then 6,50 tons $\times$ 1 ft, 05. If it be admitted, which it is nearly exact to do, that this has the effect of diminishing the load on the front axle and to increase that of the hind axle, 14 ft, 04 off, the load of the two intermediate axles not varying, the weight brought from the front behind is $p = \frac{6,50 \times 1,05}{14,04}$, that is to say less than half a ton. For the engine of the *Creusot* works (Pl. XLVI and XLVII) we have : the effort of traction 5 tns, 00 ; height of the line of traction above the rails 3 ft, 28 ; diameter of the wheels 3 ft, 94 ; width apart of the axles 11 ft, 48. The load brought from the front behind is then $\frac{5,00\,(3,28 - 1,87)}{11,48} = 0$ tns, 57.

The height of the buffers above the rails fixed ordinarily at 3 ft, 3 in carrying stock, becomes altered, either temporarily by the variable load, or in a permanent manner by the loss of elasticity of the bearing springs. The difference of the levels of the buffers of two consecutive vehicles is of little draw-

(*) Railway machinery, p. 188.

back as to traction, the vehicle which tends to be lifted up in consequence of the obliquity of the line of traction being the heaviest; but it causes, frequently enough, carriages to get off the line by lifting, which takes place the easier as the buffers of the carriages which less loaded or even empty are higher. In goods engines the height above the rails of the axis of the hind transom is almost the same as that of the centres of waggon buffers, but in passenger engines, this height reaches 3 ft, 77. This difference of level of 0 ft, 49 between the couplings of the engine and those of the train is compensated for by the vehicle which serves intermedium, that is to say the tender; the small front stops, which butt against the cross beam of the engine, and the large hind buffers have a difference of level of 0 ft, 49 and the frame of the passenger engine tender presents with this view a bend behind: a peculiarity which naturally does not exist in the tenders of goods engines.

The first are thus subjected during running to the action of a couple $t' \times h'$ which diminishes the load behind and increases it in front; t' being the effort of traction, supposed the same at the two ends of the tender, and h' the difference of level between the two couplings.

In carriages and waggons the effort of traction is applied much above the axles, about 1 ft, 64; but that has only a slight influence on the distribution of the weight, a vehicle comprised in the train being solicited at the two ends by two efforts directly opposite and very nearly equal. It is only towards the tail of the train and especially for the last waggon that the tendency to lift up behind by traction, and to lift up in the contrary direction by jamming back, becomes appreciable.

§ V. — Influence of the parts animated by relative movements.

278. *Causes and nature of the disturbances.* — The preceding disturbances are inevitable, and have to be put up with. It is not so however as regards those which we are about to investigate. If they cannot be completely got rid of by simple practical means, it is easy to reduce them enough so as to render them unobjectionable.

The relative movements of the organs of the machinery do not act only, however on the distribution of the load over the axles. This is not even their most serious effect; it is desirable to study, at the same time the others, to which same remedy applies as well.

A material system free in space, and in which interior forces develop

relative movements, is subjected to the condition of immovability, or more generally of uniformity of movement of its centre of gravity. When the partial centre of gravity of a portion of this system is displaced in a certain direction, the centre of gravity of all the rest must be displaced in the same direction but the contrary way to satisfy the enunciated conditions.

Such would be the case of a steam engine supposed to be withdrawn from every exterior force, including gravity. Such is also but less complicated, the discharge of projectiles; the centre of gravity of the system, variable at each instant, formed by the projectile on the one part and the piece and its carriage on the other, would also have an invariable position, if these masses were free in space. In reality the displacements of the carriage are reduced, or even destroyed by its want of freedom.

For the stationary steam engine, its being fastened down to the ground, and also its weight render it immovaable.

The locomotive is not free either; but this want of freedom is far from being the same in all directions. The movements in mass which would result from the condition of the invariability of the general centre of gravity may then arise or not, according to the direction, and also according to the way. But when they do not take place, the forces which would produce them if the system were free, none the less exist, and these forces may go so far as to affect the stability of the engine, just as the movements which it really takes along the directions when it is more completely free.

When a locomotive is at work, the movement of translation arises from the tangential reaction of the rails, that is to say of the utilised portion of the adhesion, an external force brought into play by the internal action of the steam; the reaction of the rails and the weight leave the system freedom enough for them to be added to the general movement of translation:

1. A linear jerking movement of the engine in the horizontal plane; this is *recoil* backwards and forwards.

2. An oscillatory movement round a vertical axis; this is *swinging*.

3. An oscillatory movement round its horizontal transverse axis; this is the *galloping*.

4. An oscillatory movement round its longitudinal axis; this is *rolling*.

These movements : the two first especially, have been long noticed. An English engineer, *Bodmer*, even pointed out a radical mean of suppressing them. This consisted in applying, on each side of the engine, two pistons working in contrary directions in the same cylinder, and acting on two cranks at 180°, placed in two vertical planes very near to each other. The principle of this expedient was disinterred, a score of years ago, by

Mr *Haswell*, engineer of the workshops of the state railways at *Vienna*. Starting from the same principle, Mr *G. Heaton* proposed to oppose to each of the masses (crank, rod, piston) animated by a relative movement, an equal mass, but of a simpler form, more concentrated, animated with the same movement in a contrary direction. But similar means are inadmissible in locomotive engines, where the space is so restricted, and where it is so important to avoid multiplicity of parts as well as passive resistances and the chances of getting out of order, and consequently of breaking down which it involves.

279. *The application of counterbalance weights is far from recent.* — According to Mr *D. Clark* (*) it is to *Robert Stephenson*, that is due, as well as are so many other fruitful conceptions, the primary idea of the means which now prevails universally, that is to say, counterbalance weights applied to the driving-wheels. Perhaps this is a case in which it may be said that *the rich only are lent to.* However that may be, *Sharp*, *Roberts*, as far back as 1837 equilibrated by counterbalance weights placed on the wheels the turning portions of the machinery (**) and, according to the same author (***), Mr *W. Fernihough*, proposed in 1845 counterbalance weights, equilibrating not only the crank and a part of the rod, but the latter entirely, as well as the piston and its accessories. He perfectly understood that this counterbalance was in excess for vertical equilibrium, but he considered the excess to be without disadvantage.

According to Mr *Clark* this counterbalance was even applied; but English engineers adhered to equilibrating what are called: the turning parts, that is to say the crank and the part of the rod supported by the crank-pin.

" It has been recognised besides " says Mr *Clark* (****), " that Mr *Fernihough*'s is not the best solution and that a counterbalance weight equilibrating 60 per cent of the masses with a relative movement suitably insures stability."

The English author limits himself to quoting the name of the engineer who the first treated in a rational and experimental manner the disturbing forces of the locomotive as well as the application of counterbalance weights thereto, M. *Nollau;* and he does not enter into any details of investigations of some extracts from which he seems only to have known of.

(*) Railway machinery; introduction, p. 7.
(**) Dito ; introduction, p. 165
(***) Dito ; introduction, p 166
(****) Dito ; p 172.

M. *Nollau*, locomotive engineer of the railway of *Holstein*, at *Altona*, published this work in the *Eisenbahn-Zeitung* of *Stuttgart* (Feb. 1848). It is little known, although it well deserves to be so. We give the translation of it in the additions placed at the end of this volume.

The first also, M. *Nollau* had the happy idea of making a locomotive work suspended by chains from fixed points, and thus to observe in a state as nearly as possible that of absolute freedom, the disturbances of the system without counterbalance weights, as well as the effects of more or less complete application thereof.

M. *Nollau's* method of proceeding has been exactly reproduced in France in an interesting pamphlet published in 1849 by M. *Lechatelier*, ingénieur en chef des mines (*).

The question has been treated analytically by M. *Desmousseaux de Givré*, in several papers to the Société des Ingénieurs civils (*Paris*) and by M. *Yvon Villarceau* in a very extended pamphlet, but little within the reach of practical men, and in which the author proposed to establish the conditions of the stability of the system in virtue of the very construction of the pieces of machinery; which leads to putting the centres of gravity of the cranks and of the connecting rods on their prolongation. M. *Résal* (**) has taken the question up again from the same point of view, but by a method a great deal simpler. The total suppression of the disturbances founded on this principle involves conditions which are incompatible, but the most important of which could be reconciled pretty nearly; the objection does not lie there; to apply counterbalance weights on the prolongation of the connecting rods would be getting into constructive difficulties, and falling on to the drawbacks of Mr *Heaton's* regulating masses, and even increasing them, in consequence of the jumping which would result from the overhanging.

M. *G. Zeuner* (***), the eminent professor formerly of the *Zürich* Polytechnic, has devoted special attention to the study of a disturbance manifested and aggravated by the presence of the springs, that is to say *rolling*.

In spite of the positive interest of these works, we shall here follow the method the principle of which was set forth in the *Annales des chemins de*

(*) *Étude sur la stabilité des machines locomotives.*

(**) *Note sur la stabilité des machines locomotives. Annales des mines,* 5 *séries* 1853, vol. III, p. 411.

(***) *Uber das Wanken der locomotiven,* in-4°, Orelli, Zurich 1867.

fer of the 21st of April 1850, and which was afterwards developed in the *Annales des Mines* of 1851 (*). I conform in this to the advice of several French and foreign engineers, who consider this method as better suited than the others, from its simplicity, to the requirements of practice.

280. I. *Horizontal disturbances.* — The centre of gravity of a system solicited by forces of any sort, moves as if these forces were all directly applied to it; the position of their points of application relatively to the centre of gravity, has only an influence on the rotation of the body round this point. The relative movements determined by internal forces do not then effect the centre of gravity in any way, because these forces destroyed each other two and two; and the movement of this centre is due to external forces.

Such is the case with a locomotive. The relative movements of the pieces of mechanism do not at all modify the position of its centre of gravity, the movement of which is determined by the external forces, that is to say by the action of the rails on the driving-wheels, gravity on an incline, etc.

When the centre of gravity of the whole of the pieces of machinery goes forwards or backwards, the centre of gravity *of the boiler and of the vehicle* is solicited by a force which tends to push it backwards or forwards, by a quantity such that the *general* centre of gravity remains unmoved. It is the displacement of the centre of gravity of the boiler that constitutes the *recoil* movement; it can be reduced or destroyed by the external forces according as they destroy partly or entirely the force applied to the centre of gravity of the fixed system : boiler, frame, wheels, etc.

Supposing even the engine to be free horizontally, that is to say the sliding friction on the journals, and the rolling friction on the rails suppressed, the *recoil* would be the only horizontal disturbance if there were only one single cylinder placed in the mean plane, or if all were symmetrical in the two driving apparatuses placed laterally (engine with three cylinders 231). But in consequence of the rectangular position of the cranks the relative movements are effected on both sides alternatively concordant and opposite; the sum of the moments relatively to the *general* centre of gravity of the forces of recoil applied to the two cranks change sign periodically as does the resultant of these forces itself, and tends to give to the boiler an oscillatory or *swinging* movement which may be, like the preceding one, and better than it, reduced or destroyed by the external forces.

(*) *Des contrepoids appliqués aux roues motrices des machines locomotives, et des limites qu'il convient de leur assigner*, par M. *Couche*. *Annales des Mines*, 5th series, 1851, vol. III, p. 427.

The value of the result out of the two recoil forces and the circumstances of this movement in the hypothesis of the freedom of the system deduce immediately from its definition.

1. *Engines uncoupled.* Let: μ be the mass of the crank; d and r the radii of the circumferences described by its centre of gravity and by the centre of the pin; B the mass of the rod; P the mass of the piston, increased if required by that of the feed pump plunger, if it is driven directly by the piston.

Let us consider running forwards and the left piston of the engine, at the beginning of its forward stroke (Pl. XXIX, *figs.* 2 and 3).

The axle having turned through an angle α, the horizontal displacement of the centre of gravity of the crank is $d(1-\cos\alpha)$. The big end of the rod describes an arc, the horizontal projection of which is: $r(1-\cos\alpha)$.

b being the length of the rod, the distance traversed by the small end as well as by the piston is:

$$aa' = r(1-\cos\alpha) - b\left(1 - \sqrt{1-\frac{r^2}{b^2}\sin^2\alpha}\right);$$

now practically, $\frac{r^2}{b^2}\sin^2\alpha$ may be neglected against 1.

The *horizontal* distances run over by the two extremities of the rod being then sensibly equal, the *horizontal* displacement of its centre of gravity is almost the same as if it were carried on parallel to itself, that is to say almost equal to $r(1-\cos\alpha)$.

In the same way we have, for the right side, the crank being (230) in the middle of its forward stroke, going from the vertical:

$d\sin\alpha$ for the horizontal displacement of the centre of gravity of the crank and of the big end of the rod;

$$DD' = r\sin\alpha + b\cos\beta - \sqrt{b^2-r^2}$$

for the displacement of the small end and of the piston: now because of

$$\cos\beta = \frac{1}{b}\sqrt{b^2 - r^2\sin^2\alpha},$$

this value becomes

$$r\sin\alpha + \sqrt{b^2-r^2\sin^2\alpha} - \sqrt{b^2-r^2}$$

or very nearly $r\sin\alpha$.

The condition of the invariability of the *general* centre of gravity, is then, M designating the mass of the whole engine and x the displacement of the centre of gravity *of the boiler and of the vehicle:*

$$[M - 2(\mu + B + P)x = \mu d(1-\cos\alpha + \sin\alpha) + (B+P)r(1-\cos\alpha+\sin\alpha)]$$

whence

$$x = \frac{\mu d + (B+P)r}{M - 2(\mu+B+P)}(1-\cos\alpha+\sin\alpha)$$

or, m being a mass such that $mr = \mu d$ (that is to say the crank *reduced to the centre of the pin*) and neglecting $2(\mu + B + P)$ against M,

$$(1) \qquad x = \frac{m + B + P}{M} r(1 - \cos\alpha + \sin\alpha).$$

a value nil for $\alpha = 0$ and $\alpha = 270°$. Its limits correspond to tang $\alpha = -1$, that is to say to $\alpha = 135°$, which gives the maximum $x' = \frac{m + B + P}{M} r(\sqrt{2} + 1)$, and $\alpha = 315°$ which gives the minimum $x' = -\frac{m + B + P}{M} r(\sqrt{2} - 1)$.

Thus the centre of gravity of the boiler goes towards the left until $\alpha = 135°$. It has then run over x'. It comes back, passes its initial position for $\alpha = 270°$, passes it towards the right by the distance x'' when $\alpha = 315°$, going anew towards the left, and returns to its initial position for $\alpha = 360°$.

The amplitude of this movement is :

$$L = x' - x'' = \frac{m + B + P}{M} r 2\sqrt{2}.$$

M. *Nollau*, and according to him M. *Lechatelier* (*), look upon the connecting rod as formed of two masses, consolidated the one with the pin, the other with the piston. They estimate in that case the centrifugal forces of the first, considered as *turning round the axis of the axle.*

The estimation of the centrifugal force applied without any explanation and without demonstration to the *fictive* mass, supposed to be consolidated with the crank, is the more likely to induce an error, as the rod turns effectively, but altogether, and round an *instantaneous* centre, placed at the meeting of the vertical drawn through the small end of the rod and of the crank prolonged, and which goes to infinity when the latter is itself vertical.

Moreover, this decomposition of the rod is not permissible as regards the vertical disturbance, and it leads to an inexact estimate of the efforts of this disturbance.

In the *Guide du mécanicien* published by MM. *Lechatelier, Flachat, Petiet et Polonceau*, the rod is considered as moving parallel to itself (**), which increases the error still further, as this hypothesis destroys the influence of the connecting rod on the vertical disturbing force. " We are not required, adds the same work (***) to analyse the movement of the connecting rod, *which could only be done by calculations of a much higher order.*"

(*) Études sur la stabilité des locomotives, p. 14 and 32.

(**) Pages 345 and 346.

(***) Page 347.

The consideration of the exact or very approximate movement of the centre of gravity is no less elementary for the rod than for the crank and the piston, and it is quite as indispensable.

Velocity of recoil, (1) gives :

$$\frac{dx}{dt} = v = \frac{m + B + P}{M} r (\sin\alpha + \cos\alpha)\,\omega \qquad (2)$$

ω designating the angular speed supposed constant, $\dfrac{d\alpha}{dt}$.

This value is 0 for $\alpha = 135°$, $\alpha = 315°$. It is maximum and equal to

$$\frac{m + B + P}{M} r\omega\sqrt{2}, \quad \text{for} \quad \alpha = 45°, \quad \alpha = 225°.$$

Force of recoil, (2) gives for the accelerating force :

$$\frac{dv}{dt} = \varphi = \frac{m + B + P}{M} r (\cos\alpha - \sin\alpha)\,\omega^2 \qquad (3)$$

expression the maximum of which, in absolute value, corresponds to $\alpha = 135°$, $\alpha = 315°$, and is :

$$\Phi = \frac{m + B + P}{M} r\omega^2\sqrt{2}.$$

We may remark that the motor force $(m + B + P)\,r\,(\cos\alpha - \sin\alpha)\,\omega^2$ is equal to the sum of the horizontal components of the centrifugal forces of two masses $m + B + P$, the one supposed concentrated on the pin of the left hand crank, the other on that of the right hand crank.

The value of φ is :

Positive from $\alpha = 0$ to $\alpha = 45°$. The centre of gravity of the boiler goes from right to left; the force acts in the direction of movement, which is in that case accelerated.

Negative from $\alpha = 45°$ to $\alpha = 135°$, and consequently contrary to the movement. The centre of gravity runs through, in effect, with a retarded movement the rest of its course from right to left.

Still negative but accelerating, from $\alpha = 135°$ to $\alpha = 225°$, the direction of the movement changing when $\alpha = 135°$, and the centre running over the first half of its course from left to right.

Positive and retarding from $\alpha = 225°$ to $\alpha = 315°$. The centre runs through, in effect, the second half of its course from left to right.

Positive and accelerating from $\alpha = 315°$ to $\alpha = 360°$, the direction of the movement having changed for $\alpha = 315°$, and the centre going from left to right, and so returning to its initial position.

Couple that produces swinging. The two components $(m + B + P)\,r\omega^2\cos\alpha$,

$-(m+B+P)\,r\omega^2 \sin\alpha$, of the recoil force taken parallel to themselves to the centre of gravity, give each a couple, which has for leverage h, $2h$ being the distance from axis to axis of the cylinders. The resultant couple that produces swinging, is then : $(m+B+P)\,r\omega^2 h \times (\cos\alpha - \sin\alpha)$; it changes direction for $\alpha = 45°$, $\alpha = 225°$, that is to say at the same time as φ.

2. *Engines with coupled wheels.* m being the mass of a coupling crank reduced to the distance r from the axis of the axle, and B' the mass of a coupling rod, the horizontal displacement of the centre of gravity of each of them would be $\pm r(1-\cos\alpha)$ for one of the sides and $\pm r\sin\alpha$ for the other: values exact now not only for the crank, but also for the rod, all the points of which describe the same circumference as the centre of the pin. The sign $+$ corresponds to engines with outside cylinders and the sign $-$ to engines with inside cylinders, the coupling cranks being keyed on in the latter at 180° to the working cranks. We have then :

1. *For engines with outside cylinders* in which $m' = m$, and where the driving crank serves at the same time for coupling:

With four wheels coupled:

$$L = \frac{2m+B+B'+P}{M-2(2m+B+B'+P)}\,r.2.\sqrt{2}, \quad \Phi = \frac{L\omega^2}{2}.$$

With six wheels coupled:

$$L = \frac{3m+B+2B'+P}{M-2(3m+B+2B'+P)}\,r.2.\sqrt{2}, \quad \Phi = \frac{L\omega^2}{2}.$$

With eight wheels coupled:

$$L = \frac{4m+B+3B'+P}{M-2(4m+B+3B'+P)}\,r.2.\sqrt{2}, \quad \Phi = \frac{L\omega^2}{2}.$$

The coupling, in engines with outside cylinders, increases thus greatly the horizontal disturbances: recoil and swinging. The resultant couple has the same leverage almost as in the uncoupled engine, the coupling rods being very near the connecting rod.

2. *For engines with inside cylinders.* With four wheels coupled:

$$L = \frac{m+B+P-2m'-B'}{M-2(m+B+P-2m'-B')}\,r.2\sqrt{2}, \quad \Phi = \frac{L\omega^2}{2}.$$

With six wheels coupled:

$$L = \frac{m+B+P-3m'-2B'}{M-2(m+B+P-3m'-2B')}\,r.2\sqrt{2}, \quad \Phi = \frac{L\omega^2}{2}.$$

In engines with inside cylinders and four wheels coupled, the masses m' and B' can be disposed so as to almost completely destroy L and Φ. But

with six wheels coupled, this point is more often exceeded, the coupling masses carry away those of the machinery, and it is then their excess $3m' + 2B' - (m + B + P)$ that produces the disturbances.

Coupling is at the same time less effective in these engines against swinging than against recoil, because the pieces animated with contrary velocities no longer move in the same plane. The coupling parts may even, while diminishing the resultant of the forces of recoil, increase their moment relatively to the centre of gravity, and consequently the swinging.

281. II. *Vertical disturbances.* — We have supposed the engine *free* horizontally. If it were placed in the same conditions vertically, if it were withdrawn from the action of gravity and of the rails, it would undergo in that direction the same effects, that is to say *vertical movements of recoil and swinging.*

The axle turning through α (Pl. XXIX, *fig.* 3), the centre of gravity of the left crank, which goes from the horizontal, is raised to $r \sin\alpha$; that g of the rod to $r \sin\alpha \frac{\lambda}{b}$ (λ designating the distance from this point g to the small end); that of the piston and of the plunger, by 0, the cylinders being supposed horizontal.

The vertical disturbing force due to the displacement of the centre of gravity of the piston in engines with inclined cylinders is a further objection against this arrangement; I shall not dwell on this because a great inclination to the cylinders is irrevocably condemned, as we have seen (273) on ample grounds.

From the right hand side, the corresponding displacements are:

$$r.(1-\cos\alpha),\quad \frac{\lambda r}{b}(1-\cos\alpha),$$

and we have as previously, L′ designating the total amplitude of the displacement of the centre of gravity for the system supposed free, and Φ' the maximum value of the force referred to the unit of mass, which produces or tends to produce this movement:

$$L' = \frac{m + B\frac{\lambda}{b}}{M - 2\left(\mu + B\frac{\lambda}{b}\right)} 2r.\sqrt{2},\quad \Phi' = \frac{m + B\frac{\lambda}{b}}{M - \left(2\mu + B\frac{\lambda}{b}\right)} r\omega^2\sqrt{2},$$

values which are deduced from those of L and of Φ relative to the horizontal disturbance, by making $P = 0$ and replacing B by $B\frac{\lambda}{b}$. If the wheels are

coupled, each pair of coupling cranks, reduced to the distance r, introduces a term $\pm m'r\ (\sin\alpha + 1 - \cos\alpha)$; and each pair of rods a term

$$\pm B'r\,(\sin\alpha + 1 - \cos\alpha).$$

We have then:

1. *For engines with outside cylinders.*

With four wheels coupled:

$$\Phi' = \frac{\left(2m + B\,\frac{\lambda}{b} + B'\right) r\omega^2\sqrt{2}}{M}$$

With six wheels coupled:

$$\Phi' = \frac{\left(3m + B\,\frac{\lambda}{b} + 2B'\right) r\,\omega^2\sqrt{2}}{M}$$

2. *For engines with inside cylinders.*

With four wheels coupled:

$$\Phi' = \frac{\left(m + B\,\frac{\lambda}{b} - 2m' - B'\right) r\,\omega^2\sqrt{2}}{M}.$$

With six wheels coupled:

$$\Phi' = \frac{\left(m + B\,\frac{\lambda}{b} - 3m' - 2B'\right) r\,\omega^2\sqrt{2}}{M}.$$

The vertical disturbing force is thus a great deal less than the horizontal one, in engines with independent wheels, and in those with coupled wheels and outside cylinders; but in engines with coupled wheels and inside cylinders, if the excess of the coupling masses causes a horizontal disturbing force to reappear, the vertical force evidently exceeds the latter by:

$$\left(B\,\frac{b-\lambda}{b} + P\right) r\,\omega^2\sqrt{2}.$$

The engine is far less free in the vertical direction than in the other. Its weight and the vertical reactions of the rails equilibrate far more than to the forces which solicit the centre of gravity of the boiler, so that there is vertically neither recoil, nor swinging.

But the pressure on the rails of the driving wheels of an engine with the wheels free undergoes a total variation:

$$2\left(m + B\,\frac{\lambda^2}{b^2}\right) r\,\omega^2\sqrt{2}.$$

It is not the whole of the recoil force $M\Phi'$ that modifies alternately more or less the pressure of the driving wheels on the rails. The vertical component of the force due to the cranks is transmitted entirely to the driving

axle; but the force applied to the centre of gravity of each of the rods is decomposed between the crank pin and the guide, so that the two rods give on the driving axle a component only equal to $\left(B\frac{\lambda}{b}r\omega^2\sqrt{2}\right)\frac{\lambda}{b}$. The other component $\left(B\frac{\lambda}{b}r\omega^2\sqrt{2}\right)\frac{b-\lambda}{\lambda}$, applied to the guides, itself is decomposed between the three axles, and is thus added to the other causes that modify the distribution of the suspended weight between the three pairs of points of support. Supposing the vertical disturbing force of the rod to be applied entirely to the driving axle, the influence of the inertia of this organ on the variation of the adhesion, is greatly enhanced.

There are thus no disturbances *in mass* in the vertical direction, affecting the whole boiler, but there may be developed under the influence of the vertical forces applied to the pair of driving wheels, partial disturbances, enhanced by the facility with which the system changes form in the region on which these forces act, in consequence of the interposition of the bearing springs.

We shall return presently to this special disturbance, taking into consideration engines completely equilibrated horizontally, which are more exposed thereto than the others.

282. *Application of counterbalance weights.* — The more or less complete suppression of the parasitical movements may be obtained in two ways: 1. by the want of freedom of the engine, in other terms by consolidating it by a very rigid coupling very tightly screwed up, with a considerable mass, naturally the tender, which increases the divisor M of the amplitude of the movements; 2. by the use of additional masses introducing negative terms into the expression of φ, as the coupling parts do in engines with inside cylinders (280).

Almost at the origin of locomotives, the balancing of the crank was done; a symmetrical appendage, or an equivalent mass placed towards the rim, brought back the centre of gravity of the wheel onto the axle. The disturbing force was thus reduced: horizontally, to

$$(B+P)\,r\omega^2\sqrt{2};$$

and vertically to

$$B\frac{\lambda}{b}r\omega^2\sqrt{2}, \text{ or } B\frac{\lambda^2}{b^2}r\omega^2\sqrt{2},$$

if the component which affects the driving wheels only is taken into account.

They soon went farther than this in England.

"It was understood *with more or less precision*," say the authors of the *Guide du mécanicien* (*) "that the effect *of the centrifugal force* had to be overcome, and there were applied, opposite the cranks, counterbalance weights equal to (or equivalent by their positions) to the weights of the *turning parts* of the engine; and to determine the dimensions of these, *the driving wheels were put in the lathe, and increasing the counterbalance weight until it balanced the weight of the crank, and of the rod suspended by its small end to a fixed point which represented the shell of the piston.*"

The mode of estimation thus indicated gives, exactly, the mass $m + B\frac{\lambda}{b}$, which applied on each wheel opposite the crank, completely destroys the disturbing force, along the vertical, that is to say that which realises equilibrium from which, now and even less than ever, is any notable departure made. This counterbalance weight reduces respectively the maximum force and the amplitude of the horizontal recoil to:

$$\left\{ B\left(\frac{b-\lambda}{b}\right) + P \right\} r\omega^2\sqrt{2}, \quad \text{and} \quad \left\{ B\left(\frac{b-\lambda}{b}\right) + P \right\} r 2\sqrt{2}.$$

What thus remains of horizontal disturbance was so far from escaping English engineers at the period to which the *Guide du mécanicien* alludes, that it was just for the very purpose of completely destroying it that Messrs *Heaton* (278) and *Fernihough* (279) proposed, the one his sliding mass equal to that of the piston and plunger, and the other his complete turning counterbalance weight, for which he had only one more step to make, and in effect, he did so.

To the counterbalance weight $g\left(m + B\frac{\lambda}{b}\right)$ for vertical equilibrium, it is sufficient to add as the complement of horizontal equilibrium, a new counterbalance weight $g\left(B\frac{b-\lambda}{b} + P\right)$ which coalescing with the first, is, like it and with it, replaced by its equivalent carried towards the rim of the wheel to a distance k from the centre (a distance as great as the radius of the wheel allows); and which is in that case $g\left(m + B + P\right)\frac{r}{k}$.

This counterbalance weight which suppresses recoil, appreciably suppresses swinging also, if the cylinders are near enough to the plane of the wheels for equilibrium to be established very nearly for each side of the engine separately; which always takes place with outside cylinders and inside frames, but very rarely with inside cylinders, especially if the frame is outside.

(*) Page 362.

283. *Effects of the counterbalance weights for horizontal equilibrium.* — 1° *Local wear of the tyres.* But this counterbalance weight, which produces more or less completely horizontal equilibrium, is excessive for vertical equilibrium, and sets up in this direction, on each side of the engine, a disturbing force much greater than that which existed before the application of the counterbalance weights.

Let us examine the effect of this force.

Before the application of a counterbalance weight, each side of the engine is solicited by a disturbing vertical force, the maximum value of which is

$$\left(m + \mathrm{B}\frac{\lambda}{b}\right) r\,\omega^2,$$

and each driving wheel by a force $\left(m + \mathrm{B}\frac{\lambda^2}{b^2}\right) r\,\omega^2$.

With the total counterbalance weight $g\,(m + \mathrm{B} + \mathrm{P})$, these forces become respectively :

$$\left\{ \mathrm{P} + \mathrm{B}\left(1 - \frac{\lambda}{b}\right)\right\} r\,\omega^2, \quad \left\{ \mathrm{P} + \mathrm{B}\left(1 - \frac{\lambda^2}{b^2}\right)\right\} r\,\omega^2.$$

By accepting this state of things, it was considered to be got quit of for a very slight reduction of the adhesion while the counterbalance weight describes its upper semi-revolution, and for an unobjectionable overload of the tyre and of the rails during its lower semi-revolution.

The influence of the periodical diminution of the adhesion has not been closely investigated for wheels with complete counterweights, which are however very rare. The limit of the horizontal reactions of the rails diminishing when the counterbalance weight rises, we can understand that the rotation might be accelerated when it approaches the end of its turn, but nothing proves, upon the whole, that this acceleration took place; that this counterbalance weight involved periodical slipping, and consequently, either a useless expansion, or even for long admissions, an improductive expenditure of steam; so that with respect to the diminution of adhesion, the disturbing vertical force which would act on the wheel could only, in effect, be of slight consequence.

But it is not the same thing, as to the effects of overloading, on the tyres and on the rails.

The tyres of the driving-wheels are submitted to tangential efforts which determine, in case of sliding especially, a *general* wear more rapid than that of the tyres of the carrying wheels; and the periodical increase of pressure due to the vertical disturbing force can determine in the portion of the tyre close to the counterbalance weight a *local wear*, *a flat place*.

A local wear is not merely the equivalent of a uniform increase of wear; it is more serious. The wheel being out of centre would impart an intolerable continuous jerking to the engine, dangerous, especially on account of the breakages of rails which they cause; the evil must be promptly remedied by turning down the wheels. The local wear requires not merely then the sacrifice of a greater thickness of metal all round the rim; it may also oblige the wheel to be put into the lathe sooner than necessary by the general alteration of the conicity, and uniform hollowing.

Its influence is at the same time greatly increased by the dependence of the two conjugate wheels in single engines; of the four, the six or the eight coupled wheels, in the others. In this last case, a *flat place* requiring the turning down of a tyre renders of course, the turning down of the whole of the five others indispensable. The causes of inequality of wear, that is to say, faults in the iron, periodical overloading, and in general the efforts which act on a given part of the tyre, must then be avoided with all possible care.

The local maximum wear ought not however to be put entirely to the account of the disturbing force; an other cause combines with that. The more or less rapid progress of the destruction of the tyre at each point, is a complex effect. The normal reaction of the rail tends to laminate and crush the tyre; the tangential reaction tends to produce a wear, in it properly so called, and the maximum amount of flattening is the result of the combined influence of these two cases.

The normal pressure at each point G (Pl. XXIX, *fig.* 4) is the sum of the statical load, Q of the wheel, of the vertical components of the forces of inertia, of the excess of the counterbalance weight, and of the effort (always directed above downwards during forward running) transmitted by the rod to the pin. Its expression is then :

$$G = Q + \left[P + B\left(1 - \frac{\lambda^2}{b^2}\right)\right] r\omega^2 \sin\alpha \pm \frac{\Pi r \sin\alpha}{\sqrt{b^2 - r^2\sin^2\alpha}}$$

α being the angle through which the axle has turned from the commencement of the forward stroke of the piston, and Π the total effective pressure of the steam on the piston, and abstraction being made of the friction. The sign + belongs to the forward stroke and the sign — to the return stroke; Π changing direction at the same time as $\sin\alpha$, for $\alpha = 180°$, the term affected by the double sign is always positive.

We may remark in passing that in engines with intermediate driving

shafts (251) the vertical components of the effort of the connecting rod no longer acts entire on the driving-wheel, but is like the suspended weight, distributed by the springs over all the wheels. This is an advantage without doubt, but very far from warranting the intermediate shaft.

The tangential pressure deducted from the equality of the moments of the two forces applied, the one to the circumference of the wheel, the other to the crank pin, is:

$$H = \pm \Pi\left(1 - \frac{r\cos.\alpha}{\sqrt{b^2 - r^2 \sin\alpha}}\right)\frac{r}{\rho}\sin\alpha,$$

ρ being the radius of the wheel, and the movement of rotation being supposed uniform.

The reality of a maximum of wear in the driving-wheel tyres has been contested. If there are grounds for this opinion now-a-days, it is solely because the improper counterbalance weights for horizontal equilibration have disappeared. By examining a certain number of tyres to which this counterbalance weight had been applied, I verified, on nearly all of those the general wear of which was marked, the existence of a well defined maximum of wear. Further the middle of this region did not correspond to that of the counterbalance weight, but very considerably *preceded* it.

This apparent anomaly is explained by the almost continual application of a lengthened expansion. If Π were constant, G and H would each be a *maximum*, both of them for $\alpha = 90°$. The maximum amount of flattening ought then to correspond exactly to the mean radius of the counterbalance weight. But as Π is decreasing before the piston has reached the middle of its stroke, the *maximum* of G and that of H no longer coincide. That of the second term of G and that of H correspond to less values; and the total maximum corresponds in that case to a value of α intermediate between 90°, the relative limit to the pressure due to the counterbalance weight, and a value as much below 90°, as the period of admission is shorter.

Π_1 being the constant pressure during the admission, α_1, the value of α at the moment when the expansion commences, k the height of a cylinder of the same section as the piston and of the same volume as the clearance and the steam passage, we have, supposing that the expansion takes place according to *Mariotte's* law:

$$G = \left\{\left[P + B\left(1 - \frac{\lambda^2}{b^2}\right)\right]\omega^2 + \Pi_1 \frac{k + r(1-\cos\alpha_1)}{[k + r(1-\cos\alpha)]\sqrt{b^2 - r^2\sin^2\alpha}}\right\} r \sin\alpha,$$

$$H = \frac{\Pi_1}{\rho}\cdot\frac{k + r(1-\cos\alpha_1)}{k + r(1-\cos\alpha)}\left(1 - \frac{r\cos\alpha}{\sqrt{b^2 - r^2\sin^2\alpha}}\right) r\sin\alpha,$$

expressions the maximum of which can only be determined by trying.

The fact of the displacement of the maximum of wear seemed to me very clear, and several engineers have told me that they have also observed it. The examination of the tyres requires, at the same time, a certain amount of preciseness, a *flat place* very sensible by its effect, may easily not be so to the eye or to the touch. It is only then in the lathe, that the position of the maximum of wear can be with exactness determined, unless it is very decided; an iron template may also be employed, cut out exactly according to the normal profile of the wheel at the middle of the tyre, but this means requires care.

The region of local wear was naturally of some extent, and this extent was in a manner the complex expression of the variations of the speed, of the expansion, and of the pressure during admission. It was in fact a fortunate occurrence. If, in consequence of the constancy of these elements, the action had been concentrated on the same point, it would have produced a sudden *flat place* similar to those which result from prolonged skidding by brakes, the consequences of which are a great deal more injurious than with gradual going out of centre.

We might have expected to find also a maximum of wear in the neighbouring portion, not of the maximum of G, but on the contrary, of its minimum. It would have been the sign of slipping being produced whenever the adhesion should become, from want of load, inferior to the value H. But the absence of a flat place in this portion confirmed the opinion just expressed.

The influence of the periodical extra weight on the rails not shewing itself, as in the case of tyres, by the accumulation of effects on the same portion, it was almost as impossible to verify it, as to question it; it is very probable even that it would more seriously affect the permanent way than the driving-wheels. The tyres would only undergo, altogether, in consequence of the suppression of the vertical equilibration, a sort of rolling; while for the rails deflected transversally it would be a question of a very considerable overload and necessarily very often applied in the most unfavourable manner (I, 68 and following). What is the use of endeavouring, in the statical distribution of the suspended weight over the axles, to strictly limit the pressures on the driving-wheels, to what is required for adhesion, if no scruple be afterwards made to admit extra weight, periodical only, it is true, but enormous?

And this is not all.

2. *Driving-wheels running off the line.* — There is a danger which might

have been called chimerical, but of which experience has undertaken to prove the reality; that of the running of the driving-wheels off the line being lifted up by forces of inertia of the excess of the counterbalance weights. On four different occasions, driving-wheels of *Crampton's* engines ran off the line in this way on the Northern of France under the influence of the counterbalance weights for horizontal equilibration; and these accidents would have certainly increased if they had not been put a stop to, by the reduction of the counterbalance weights, so thoughtlessly made into elements of instability.

The builders however did not allow themselves to be so misled. Thus after the mishaps on the Northern of France, the company of the Eastern of France wished to make sure that the equilibrium of their *Crampton's* engines, with regard to which it had put itself into the hands of the engineers of the firm of *Cail and Co*, should not expose it to similar mischances.

"I have the honour to inform you, answered "M. *Houel*, the engineer," that according to the indications of M. *Lechatelier* the counterbalance weight to be placed on each driving wheel of the *Crampton's* engines of the *Strasbourg* line would be 238 pounds placed diametrically opposite to the crank. But *not having dared to take the risk of the use of so great a counterweight* for the first *Crampton's* of the Northern of France, we have reduced it 1,8 times; and as these engines have run perfectly, without any unsteadiness, we have kept to this same equilibration for our other *Crampton* engines. Those of the *Strasbourg* line, are thus equilibrated by a counterbalance weight equal to $\frac{238}{1,8} = 131$ lbs."

"Paris, 26 October 1853."

The Eastern of France regained confidence.

On the occasion of the three first times the *Crampton's* engines ran off the line, the Northern of France at first reduced their counterbalance weights by 25 per cent. "But", says M. *Lechatelier* in a note read at the *Société des Ingénieurs civils* (*).

"One of *Crampton's* engines, having only three counterbalance weights instead of four, having recently run off the line for the fourth time, the partial counterbalance weights, the original counterweights were returned to."

And he adds :

"Is it a drawback of the counterbalance weights, their not being able to be applied to

* Extract from the Proceedings of the *Société des Ingénieurs civils.*
Meeting of the 14 November 1853.

Crampton's engines, or a drawback to *Crampton's* engines their not being able to take counterbalance weights which would be so useful for their own preservation, and even for that of the permanent way?"

A question quite easy to answer. The *Crampton's* engine can perfectly well take counterbalance weights. These are very useful to them, but on condition of not being exaggerated. Vertical equilibration is sufficient for it, and all the more so, that the great distance apart and great load of its end axles, themselves very efficiently oppose to swinging.

We see what its stability, in that case irreproachable, becomes with horizontal equilibration; and as to the permanent way; what it would gain therein would be an enormous periodical extra strain.

To run off the line in this manner, requires without doubt the combination of divers circumstances; first of all great speed, perhaps rocking of the boiler, and a great pressure of one of the flanges of the driving-wheels against the rail, tending first to cause the flange to slide, and afterwards getting off the rail once the flange clear.

It is easy to see without supposing any cause, that the disturbing force due to the excess of the counterbalance weight would be almost sufficient to determine the separation of the wheel and the rail.

The piston weighs, with its rod and cross head..........	350 lbs.	We have : $r = 0^{ft},90$
The plunger	44	and $\frac{\lambda}{b} = \frac{3}{5}$ (about)
The connecting rod..................................	298	
The crank..	132	
Counterbalance of horizontal equilibration, brought to the centre of crank pin	824 lbs	

A speed of 56 miles an hour (83 feet per second) is frequently attained in the running of *express* trains. The wheels being 6 ft, 89 in diameter, $\omega = \frac{82}{3,445} = 23,81$. The corresponding value of the disturbing force applied to the wheel, at the instant when the crank is vertical and below, is with the horizontal equilibration : 9.290 lbs.

The engines in question weigh 27 tons full; the middle axle ought not, while at rest, to carry as much as the end ones, but it is certainly not going too far to admit that a very sensibly uniform distribution or 4 tons, 50 per wheel is frequent enough during running.

Equality is thus nearly reached without making any forced hypothesis, without going out of the conditions of work; the disturbing force is almost sufficient for the wheel to do no more so to say than touch the rail. When

the limit is so near, it will be easily understood that, under the influence of the accessory causes indicated, the pressure on the rail may become altogether *nil*, not only at the instant when the radius of the balanceweight passes the vertical, but even sooner, in which case the wheel would be lifted: and independently of all application of flanges against the rails, the amplitude of this lifting, every thing else equal, would be so much the greater the more flexible the bearing springs.

We have considered one wheel only. Each wheel can in effect, in spite of its connection with the other, yield freely within certain limits, to the dis turbing force which is immediately applied to it, the separation of one wheel and the rail does not thus necessarily imply uplifting the axle bodily. Alternate uplifting is possible, while simultaneous uplifting is still not so, because for the latter the mass is double, but the force greater only in the ratio of $\sqrt{2} : 1$. The first may at the same time, quite as well as the second, if not more so, degenerate into running off the line; it is the latter therefore, that should be considered.

284. *Uplifting of the wheel.* — Let us dwell a little on the analysis of this movement.

Let: gR be the weight of the wheel; p the mass $P + B \times \left(1 - \frac{\lambda^2}{b^2}\right)$, which the force of inertia solicits vertically; α the angle of the mean radius of the counterweight with the horizontal; ω the constant angular speed.

Let us suppose the wheel at first unloaded, and let us seek the law of its vertical movements, the condition $p r \omega^2 > g R$ being supposed satisfied.

There is in that case an angle $\alpha_1 < 90°$, such that $p r \omega^2 \sin\alpha_1 = g R$. The wheel will commence to lift as soon as α exceeds α_1; the accelerating force will increase until $\alpha = 90°$; it will decrease afterwards, but will remain positive until $\alpha — 180 — \alpha_1$. Then the speed will commence to slacken; it will become nothing for a value α_2 easy to determine. The wheel will commence then to descend, with a rapidly accelerating movement, will create a shock on the rail, and will remain without vertical velocity until α equals and surpasses anew α_1.

We have:

(1) $$\frac{pr\omega^2}{R}\sin\alpha - g = \frac{dv}{dt} = \frac{dv}{d\alpha}\frac{d\alpha}{dt} = \omega\frac{dv}{d\alpha};$$

whence

(2) $$v = \frac{1}{\omega}\int_{\alpha_1}^{\alpha}\left(\frac{pr}{R}\omega^2\sin\alpha - g\right)d\alpha = \frac{pr\omega}{R}(\cos\alpha_1 - \cos\alpha) - \frac{g}{\omega}(\alpha - \alpha_1),$$

a maximum expression for

$$\sin\alpha = +\frac{gR}{pr\omega^2},$$

and $\cos\alpha$ negative, that is to say for $\alpha = 180° - \alpha_1$, which is evident *a priori.*

This maximum is:

$$V = \frac{2pr\omega}{R}\cos\alpha_1 - \frac{g}{\omega}(\pi - 2\alpha_1).$$

The space run over is:

$$e = \frac{1}{\omega}\int_{\alpha_1}^{\alpha} v d\alpha = \frac{pr}{R}[\sin\alpha_1 - \sin\alpha + (\alpha - \alpha_1)\cos\alpha_1] - \frac{g}{2\omega^2}(\alpha - \alpha_1)^2. \quad (3)$$

and making $\alpha = \pi - \alpha_1$, we have for the lifting at the instant when the acceleration ceases:

$$e_1 = (\pi - 2\alpha_1)\left[\frac{pr}{R}\cos\alpha_1 - \frac{g}{2\omega^2}(\pi - 2\alpha_1)\right].$$

the wheel continues to lift until α equals the value α_2 which satisfies $v = o$, an equation which can be resolved only numerically.

This value brought over into (3) would give the total amplitude E of the uplifting.

Beginning at $\alpha = \alpha_2$, v is negative, the wheel falls back, e decreases, and the value α_3 deduced from $e = 0$ would fix the position of the point of the rim at which the wheel would encounter the rail, point which would be always the same for a uniform speed; *and which would in consequence be indicated by a maximum of wear, more or less distant from the counter-balance weight.*

By making, in (2), $\alpha = \alpha_3$, we should have the vertical component of the speed with which the wheel would bring a shock on the rail.

Let now gQ be the normal load on the wheel.

If the condition $pr\omega^2 > g(R + Q)$ were satisfied, and, *if the system were rigid*, it would be sufficient to replace in what precedes, R by R + Q (in neglecting the consolidation of the weight gQ with that which the other axles carry).

But it is no longer so, when presence of the bearing spring is taken into account. The theoretical condition of the initial uplifting of the wheel is the same, but the circumstances of this movement change. When the system is supposed rigid, the wheel cannot lift without the load gQ rising by the same quantity; when the system is flexible, the elevation of the load during the very short space of time of the ascending movement of the wheel may be much deal less, and even almost nothing. (The ulterior release of the spring would also very little affect the load, because it would act chiefly, in consequence of the rapidity of the rotation, during the fall of the wheel, that is to say at the middle of the spring and not at its extremities).

The amplitude of the lifting would evidently increase, every thing else equal, with the flexibility of the spring. f being its statical deflection under the load gQ, α and φ the simultaneous values of the inclination of the radius running to the centre of the counterbalance weight, and of the increase of the deflection due to the lifting of the wheel and to the inertia of the boiler, the reaction of the spring at the same instant would be : $gQ\frac{f+\varphi}{f}$, and the equation (1) would become

$$\frac{pr\omega^2}{R}\sin\alpha - g - \frac{gQ}{R}\frac{f+\varphi}{f} = \omega . \frac{dv}{d\alpha},$$

with the condition:

$$\varphi = \int vdt = \frac{1}{\omega}\int_{\alpha_1}^{\alpha} vd\alpha.$$

But in practice, the condition $pr\omega^2 > g(R + Q)$ is never or hardly ever satisfied, so that the lifting would be impossible without the influence of the forces of inertia, due to the movements which the inequalities of the line convey to the suspended mass. These movements which however do not follow any assignable law, might have the effect of reducing accidentally the load on the driving axle, to such an amount that the condition of the lifting may be fulfilled.

285. Altogether, the trials of the counterbalance weight for horizontal equilibration, have only resulted in failure.

" It is only a short time since," said the *Guide du mécanicien* in 1851 (*), that the exact appreciation of the causes of instability that we have analysed has permitted their *rational and complete neutralisation* to be arrived at, by means of great practical simplicity."

This was and is always an error; the neutralisation obtained through counterbalance weights is neither rational "nor" complete.

" What is constant," wrote also M. *Lechatelier* (**) is, that if, by counterbalance weights, the effect that ought to have been expected was not obtained, is that *too slight dimensions have always been given to them.* "

The application of counterbalance weights has been sometimes too much neglected; engines have been seen and are seen even still, entirely unprovided with them. This is often a mistake. But the exaggeration of

(*) Page 360.

(**) *Sur la stabilité des machines locomotives*, p. 70.

counterbalance weights is not less injurious then the want of them. Happily, the practical sense of builders put them on their guard against this exaggeration: they understood perfectly that in overpassing the aim, the same rock would be struck against, to avoid which is the aim of counterbalance weights.

We have already cited (283) the example of the builder of the *Crampton's* engines of the Northern and of the Eastern of France.

" We have kept to vertical equilibration or nearly so," said M. *Beugniot* (*) on the subject of one of his engines, to which we shall soon return, " and the stability of our engine proves that we have done right; we should have feared by going further to overstrain the tyres and the rails."

The new high speed engine (Pl. XXX to XXXII) constructed by the same engineer according to the program laid down by the Northern of France company, received also only small counterbalance weights, forming, in order to arrive at vertical equilibration, the difference of the coupling pieces, which are insufficient to equilibrate the great hooped cranks of the axle, and the part $B\frac{\lambda}{b}$ of the rod.

If there is moreover a point on which every one is agreed, it is this. A writer, already cited, M. *Petzholdt*, has well interpreted the opinion of German engineers, when he says in a quite recent work (**):

" It is by the system itself of the engine that the disturbances must as much as possible be combatted, without laying too much stress on equilibrating the forces by revolving masses. Experience has proved that at a high speed the large counterbalance-weights hammer the rails, and wear the tyres in places."

Here is from another side how the question is summarised in an important document (***); it was put in these terms:

" What does experience indicate, as to the action exerted by the forces of inertia of masses animated with relative movements, on the rapidity and the inequality of wear of locomotives tyres?"

(*) *Bulletin de la Société industrielle de Mulhouse,* October and November 1860, p. 488 and 530.

(**) *Fabrication, Prüfung,* etc., 1872, page 137.

(***) *Referate über die Beantwortungen der für die V. Versammlung der Techniker Eisenbahn-Verwaltungen aufgestellten Fragen.*

These reports which do not seem to have been yet published separately, appeared in the *Organ für die Fortschritte des Eisenbahnwesens,* Year 1871, p. 108.

The drawer up of the report commences by establishing that:

" Almost all the managements have verified this injurious influence, that is to say, the existence of a maximum of wear at certain points."

And he concludes thus:

" With suitable equilibration this action is insignificant, but it is increased, either in high speed engines, when required with a view to improve their steadiness, to equilibrate more than the revolving parts, or in goods engines, when the smallness of their wheels does not permit them to attain vertical equilibrium."

286. *Distribution of the counterbalance weight between the two conjugate wheels, when there is a great distance between them and the axis of the cylinders.* — When the distance d of the two vertical planes passing, the one through the axis of the cylinder, the other through the middle of the wheel on the same side, is too great, the two contrary forces are too far away from direct opposition, for the equilibrium of rotation to be established on each side of the engine, even were the equilibrium of translation to take place. But thanks to the solid connection of the two conjugate wheels, nothing is simpler than to bring back the resultant of the compensating forces of inertia so to act exactly in the same vertical plane as the disturbing forces. It is sufficient for that, instead of applying the whole of the counterbalance weight K on the wheel A, to distribute it over this wheel and over its conjugate wheel B; the first receiving, if the cylinders are inside (Pl. XXIX, *fig.* 5), $K\frac{e-d}{e}$ and the second $K\frac{d}{e}$, and these counterbalance weights being placed in the same direction, that is to say opposite to the crank. By proceeding in the same way on the other side, we have on each wheel two counterbalance weights, the one $K\frac{e-d}{e}$, at 180° of the crank, the other $K\frac{d}{e}$, at 90°, which are combined in a single one (*fig.* 6). This final counterbalance weight is

$$K\sqrt{\left(\frac{e-d}{e}\right)^2+\left(\frac{d}{e}\right)^2}=\frac{K}{e}\sqrt{e^2-2de+2d^2},$$

a value reduced to K if $d=0$.

If the cylinders are outside (*fig.* 7), the wheel next to the cylinder we are considering, receives $K\frac{e+d}{e}$ opposite the crank, and the other

wheel, $K\frac{d}{e}$ at 180° from the first counterbalance weight; and the total counterbalance weight on each wheel is:

$$\frac{K}{e}\sqrt{e^2+2de+2d^2}.$$

In fact, account is very rarely taken of this discrepancy between the directions of the contrary forces.

287. *Distribution of the counterbalance weight over several wheels of the same side in the case of coupling.* — If the cylinders are outside, and the engine has six wheels coupled, the counterbalance weight for vertical equilibration is $g\left(m + B\frac{\lambda}{b} + 2m + 2B'\right)$, and the mass which makes the load of the driving wheel vary, supposed at the middle, is:

$$m+\frac{B\lambda^2}{b^2}+\frac{B'}{2}+\frac{B'}{2}.$$

The theoretical counterbalance weight, that is to say referred to the centre of the crank is, then very considerable, and the effective counterweight is so itself because of the small diameter of the wheels and in consequence of the slow speed. The form even of the counterbalance weight reacts on its size and reciprocally. It ought in effect to occupy towards the rim, a more extended arc (Pl. XLIX) or a more complete sector (Pl. LXI, driving wheels K, K) the heavier it is (*); more nearly its centre of gravity approximates to the centre of the wheel, and its leverage so much the smaller is. This difficulty is avoided by taking advantage of the relative invariability of position of wheels coupled the same side, to distribute the total counterbalance weight amongst them; this distribution can be done in such a manner to make the variation of the load on the rails, according to the inclinations of its crank, disappear almost for each wheel.

The application of horizontal equilibration would in consequence of this division, be less inconvenient for engines with coupled wheels, than for uncoupled engines, and the better as the weight which measures the difference of the two equilibrations is the same with or without coupling. But the slightest is already very considerable, with outside cylinders.

As to swinging, the disturbing masses move in two different vertical

(*) Sometimes also the counterbalance weight is limited towards the inside by an arc of a circle, of a greater radius than at the outside; its form is almost then that of a segment of a circle.

planes, if the two coupling rods are in the same line with an articulation, and in three planes if these rods are separate, that is to say, placed on both sides of the driving rod. The distance between these planes and that of the regulating masses is inconsiderable; but it becomes so if the frame is outside like the cylinders; and it would be easy to take into account by determining on each side the position of the resultant of the disturbing forces, equilibrating it by two counterbalance weights, applied the one to one wheel and the other to its conjugate, and composing afterwards the two counterbalance weights of the same wheel into a single one.

If the cylinders are inside, the coupling parts, act, as has been already remarked, as regulating masses, but there is an excess, if the six wheels, or still more the eight wheels are coupled, and more again, if the frame is outside, which increases the excentric mass of the cranks; recoil thus reappears, and the equilibrating mass ought then to act in the direction of the parts of the machinery, in order to compensate for the excess of the masses of the coupling. It is for the vertical equilibration:

$$3m' + 2B' - \left(m + B \quad {}_b\right).$$

The distance between the planes in which the respective masses accomplish their movements might besides in these engines as in the preceding ones, lead to neutralising the disturbing forces on each side, by counterbalance weights distributed over the two wheels.

288. *Engines equilibrated by four pistons.* — *Figs.* 7 and 8 of Pl. LXXVIII, give a general idea of the engine in which M. *Haswell*, carried out Mr *Bodmer's* idea (278) (saving the substitution of two cylinders for a single one, receiving the two pistons going in contrary directions). The complication is somewhat less than would have been supposed by the simple enunciation of the principle. If, in effect, the organs of the driving machinery proper are double, those of the distribution are simple, thanks to an ingenious contrivance. Each steam port corresponds by half its section to the face of one of the pistons, and by the other to the opposite face of the other piston. But although reduced, the complication for all that remains very considerable; the double crank $\alpha\beta\gamma$ works under very unfavourable conditions; lastly, the equilibrium is not perfect, the distance 0 ft,40 between the vertical planes passing through the axes of the two cylinders, leaving a couple subsisting on each side, which is however easily destroyed by the connections of the system. The *recoil* is completely des-

troyed, it is true, but as that is in no way necessary, it is satisfactory from a purely theoretical point of view only, and out of all proportion with what it costs.

Thus the experiment made on one engine, out of a series of twelve, simply resulted in the application of the ordinary counterbalance weight to the others.

Vertical equilibration, which engineers and builders were right not wishing to exceed, and which was sufficient fifteen or twenty years ago to insure stability, is sufficient, with greater reason, now-a-days, in spite of the increase of speed.

More careful building and maintenance of engines, the parts of the machinery relatively lightened, a better distribution of the weight over the axles, lastly the greatly improved state of the permanent way, reduce remarkably the effect of what still remains of disturbing force.

CHAPTER VI.

DETAILS OF THE VEHICLE.

§ I. — Suspension.

289. *Form of ordinary springs.* — The spring of plates placed one over the other and increasing in length to the top, which after pretty numerous trials of different forms is as we have seen (68, 74), almost generally adopted for carrying stock, is nearly the only one in use on locomotives. We have cited (67) the application made by Mr *J.-Edwards Wilson*, of plates of the same length, of a uniform thickness, coming to a point, and realising thus, the equality of resistance by the triangular form on plane, instead of doing it by a parabolic section. The same form has been adapted for the engines of the *Indian Branch Railway* (Pl. LXXIX, *fig.* 6) but it does not seem to be attended with any advantage. In locomotives, the decreasing (69) of the plates begins, ordinarily, only at the third or even the fourth plate, in order to leave the ends of the spring sufficient resistance. This is especially necessary when, according to the arrangement greatly adopted in France, the load of the frame is brought on to the spring by means of rods passing through holes pierced in the extremities of the upper plates (Pl. XXIV, XXVIII, XXXI front axle; XXXIII, XXXVII). These holes ought to be ovalised according to the length of the spring in order that, in the deflections of the system, the rod may not touch the edges of the plates, as that might cause them to break, and would besides oppose their freedom of play, which is already hindered with by their mutual friction. The rod is screwed and receives a nut which brings the load on to the thickened end (Pl. XXIV, XXVIII, XXXV, etc.) of the main plate, this thickening having for object to compensate partly for the loss of matter, and to keep the strain always applied to the same point, when the deflection of the spring, and the inclination of the spring rods vary. It also prevents the rod from getting out of place, as the hole is larger than the rod; this is effected by means of a washer placed between the nut and the spring, and presenting two

lateral notches into which the thickenings penetrate, and so fix the position of the washer. Sometimes the main plate stops at these enlarged portions (Pl. XXIV and XXV), sometimes it is prolonged beyond and to the same length as the plate on which it rests (Pl. XXVIII, XXXIII, XXXVIII, XLVIII, LV, LXI). A great many engines will be found to pass from the second case to the first, in consequence of the fracture of the main plate beyond the enlargement, an amount of damage which does not involve its being replaced.

It is by means of the nuts, the check-nuts of which prevent their loosening, that the distribution of the weight varies between the limits which result from the conditions of construction of the engine (265). Making a hole in the plates can be avoided by curving the upper end of the spring link so as to hook onto the thickened extremity of the upper plate, and the nuts are in that case applied to the other end of the spring link (tank-engine of the *Creusot*, Pl. XLVI; eightwheeled coupled engine of the Northern of Spain, Pl. XLIX; engine of the *Saint Leonard* Company, Pl. XLV, etc.). Sometimes also the main plate has the end not simply turned up as in carriages and waggons, but very considerably thickened with a horizontal cylindrical hole made, receiving a bolt which effects the fastening of the spring by means of a stirrup. Another stirrup is jointed on to the frame, and united to the first by a screw with right and left hand threads, by means of which the load is regulated. This arrangement, which requires some complicated work for the main plate is frequent enough, especially in engines with outside frames (*ee*, Pl. XXV).

290. *Divers positions of the springs.* — Each journal often has, in engines as well as in waggons, its special spring, placed directly over the longitudinal, which is suspended to it by the rods ordinarily forked at the lower part, and the spring clip rests on a stirrup which passes over the longitudinal and brings the load onto the axle-box (Pl. XLI, *fig.* 1 and *fig.* 2, R, *l*). However to avoid cutting into the flanges of the longitudinal when it has the section of a double T, the spring links are jointed on to shoes fixed to the web by bolts which work in that case in traction (Pl. XX, *fig.* 1, Pl. XXI, *figs.* 1 and 2). As the two last figures indicate, M. *Krauss* only fixes each shoe by two bolts; M. *Mesmer* has prudently put four.

With outside frames this position of the spring does not ordinarily present any difficulty. But sometimes, to leave the upper surface of the longitudinals free, to fit thereon, for example, the cylinders (*Buddicom's* engines) or water tanks, a part or even the whole of the springs is

brought under the frame; and then, if there is want of space between the lower surface of the longitudinal and the axles boxes, the spring has almost always to be brought underneath and suspended to the box (*Crampton's* of the Northern of France, Pl. LXXVIII, *fig.* 1).

With inside frames the difficulty for powerful and high speed engines and consequently with large boilers and large driving wheels, results from the very slight space between the sides of the boiler, those of the fire box especially, and the wheels. For engines with small wheels where the diameter of the boiler may as we have seen (235) exceed, even greatly, the distance apart of the wheels, a moderate amount of raising of the boiler permits the springs to be lodged under the barrel. But the difficulty subsists for the hind springs as regards the fire box, unless in the case where the latter being considerably narrowed, would leave sufficient room between its sides and the wheels, such as we see an example of in the Western of France engine (Pl. XLI, *figs.* 1 and 2); but this is not an example to be imitated, as what is required is on the contrary, to give the fire-box the greatest possible width; and then the hind axle, whether placed in front of the fire-box or behind, is always too near to admit of ordinary springs; they would be too short to have at the same time the resistance and flexibility required. Rigorously speaking, these two conditions can be fulfilled with short springs, putting two together one over the other, the deflexions of the two are of course added; this is the double spring, which long has been greatly in use in ordinary carriage building. But it is complicated, subject to disarrangements, and its application to locomotives, to *la Rampe*, for example, with eight wheels coupled of M. *Beugniot* (Pl. LXXX, *fig.* 4, ρ, ρ); to la *Puébla*, an engine with six wheels coupled constructed at the *Creusot* works for the *Méditerranée* lines, etc., did not give good results. Thus its only use now-a-days is as buffing and drawing spring (*t*, *t*, Pl. XLVI and XLVII). It is generally preferred to keep to the spring with plates in layers, under the axle boxes, and often too at a very small height above the rail, as in the altered engine of the *Méditerranée* (ρ, ρ, Pl. XXXVIII, and XXXIX). The same arrangement is found in the locomotive with six wheels coupled of the *Midi* (ρ, ρ, Pl. XXXVIII, XXXIX and XL, *fig.* 5); 2, for the two hind axles of the engine with eight wheels coupled of M. *Kœchlin* (ρ, ρ, Pl. LV to LVII).

In other cases, it is, on the contrary, by raising the spring up that the necessary arrangement is managed. The two symmetrical springs, thrown by the boiler out of plumb with the longitudinals, are placed overhanging on a cross beam H, which brings the load over onto the axle-boxes by the

thrust pins connected with it *o*, *o*. The suspension links are loaded by means of brackets rivetted onto the outside face of the longitudinal, and by projecting the horizontal distance therefrom of the spring (XLIII to XLV), engine of the Western of France (Pl. XLVI and XLVII) engines with six wheels coupled of the *Creusot* works; Pl. XLVIII, engine with eight wheels coupled of the *Orleans* railway, hind axle; Pl. XLIX to LII, engine with eight wheels coupled of the Northern of Spain, third and fourth axles).

An other arrangement adopted by M. *Koechlin*, consists in still placing at a distance apart, and raising up the two springs, to which the boiler is itself directly fixed, and not the frame; curved thrust pins bring the load onto the cross beam, which itself transmits the load to the axle boxes by thrust pins. This arrangement is neither simple nor exempt from other drawbacks, were it only that of directly connecting the boiler, instead of the general base of support of the frame.

This difficulty of placing the hind springs, has been worked out in a thorough manner in a passenger engine of the *Charentes* railway. This engine has outside cylinders, and four wheels coupled of 5 ft, 58 in diameter, and overhanging fire-box. The two first axles are loaded by the general frame, which is an inside one. The hind axle is loaded by a partial outside longitudinal, so as to bring as near together as possible the plane of the wheel and the coupling rod, which latter drives a *Hall's* crank journal (234), in cast steel.

Another solution applicable to the same case is the cross spring (*quer Feder*) loaded by a double stay, bolted onto the longitudinals, and the extremities of which rest on the axle-boxes (R, Pl. XXI, *fig.* 1; *Krauss's* engine). In thus getting out of the difficulty of placing the springs, there is the further advantage of dividing the load equally between two conjugate wheels, from which point of view this spring assimilates to a compensating beam, which we shall shortly come to.

Figs. 19 and 20, Pl. LXXXVII, represent an analogous and old arrangement; but the load is applied by the intermedium of a spindle I to the spring clip, the ends of the spring being jointed with links *m* instead of resting simply on the axle-boxes.

The hind suspension is more complicated still, in the engine with six wheels constructed by *Schwartzhopf* of *Berlin* for the Hanover railways. The cross spring with its concavity upwards and loaded by links is suspended from a spindle between two lugs which bring the load on to the axle boxes. Complete freedom results from this, for the axle to incline to the

line, without the two wheels ceasing to be equally loaded. If a certain play is given to the axle-boxes to facilitate running through curves, the unequal inclination of the two clips sets up a force which brings back the axle to its normal position and which this play renders necessary and to which we shall soon return.

Among the engines in which suspension on the hind axle requires special arrangements, is the *Crampton* properly so called, that is to say, with the driving axle taking the load from inside longitudinals. To lodge the longitudinal springs between the great wheels and the boiler, the springs must be raised up to the height where the diminution in the breadth of the cylindrical crown of the fire-box shell leaves sufficient space between it and the wheel. The frame is suspended only to the hind spindle; the front spindle is fixed directly on to the boiler. The thrust pin is simple (which by the way is its ordinary form) and applied against the inside face of the longitudinal. Its bearing on the axle-box is thereby brought towards the middle of the length of the box.

Springs raised up in this manner are rather inconvenient for the driver, whose movements they hinder. They were replaced in a certain number of the Méditerranée *Crampton* by a transverse spring; but this could not evidently have been placed on the axle (249). It was obliged to be placed underneath, suspending it from the axle-boxes, and carrying the load on its centre by mean of a special socket piece. But this modification was soon abandoned; it was rightly complained of for complicating the application of the load on the spring as well as the inspection of the boxes which in that case required the spring to be taken down.

Ordinarily placed exactly over in the case of inside longitudinals, the springs may also, when required, be placed on one side, either outside or inside. This third position is a great deal more frequent than the second; it allows the maximum distance to be given between the longitudinals, and a greater length to the axle-boxes, while at the same time loading them almost uniformly or at least at their middle. The spring placed on one side of the longitudinal, receives the load by means of brackets with such a projection that the longitudinal axis of the spring comes exactly over the transverse axis of the journal. The only drawback to this arrangement is to reduce slightly the breadth of the elastic base; but long journals and the application of the load nearly at centre, are advantages positive enough for something to be sacrificed for them.

The high speed engine ot the *Orleans railway* (Pl. XXXVI) and the eight wheeled engine of the *Ceinture* railway constructed by Messrs *Koechlin* and

Co (Pl. LV to LVII) offer examples of this; in the second, the distance apart of the longitudinals is 4 ft,03, and the springs are placed between them; the two front ones R, R, above the axles, the two hind ones ρ, ρ, below. The fire-box, which does not go far down, allowed at the same time an axle to be placed under the fire-grate, protecting it by a simple bend in the ash-pan. In spite of the unfavourable position, in appearance, of inside axle-boxes, the proximity of the fire has no objectionable effect.

In Germany, and especially in Austria, these difficulties of placing springs are met pretty frequently by the use of *Baillie's* spring (74). The same element strictly speaking can be applied to all circumstances of load and flexibility. The required resistance is obtained by placing together a suitable number of elements, (Pl. LXXXVII, *fig.* 18) and the flexibility by superposing two rows (*fig.* 16), sometimes even three. The compression of each volute is regulated by means of a screwed spindle and of a nut which rests on the neck of the steel plate. This spring is above applied at times also in the line of the longitudinal (*fig.* 17). It is as wide as the laminated spring, but it occupies less length.

Often also, by the use of springs common to two journals, small girders and compensating beams, the difficulties of managing the suspension are got over; but the object of these appliances is also and especially to carry out, either partly or entirely, the distribution of the weight, and we shall examine them at the same time from the two points of view.

§ II. — Means of realising a given statical distribution of the weight.

291. *Conditions which the distribution of the weight ought to satisfy.* — We need not dwell on four-wheeled engines, in which only one single distribution is possible.

With three axles it may be proposed to fulfil more or less completely a set of conditions, which depend, at the same time, on the functions of the engine.

If it has to run at a low speed, and consequently having all its wheels coupled, and of the same diameter, only one single condition requires to be attended to : as equal as possible distribution of the load between the three pairs.

For high speed engines with the wheels free, there are two conditions to be brought into accordance ; adhesion sufficient to insure particularly rapid starting, and perfect stability. An almost uniform distribution would not

give enough adhesion; load on the driving axle ought considerably to exceed a third of the weight. As the leading axle guides the engine, its running off the line of which would involve generally the whole thing running off a system, it should be kept on the line by a considerable contingent. But care must be taken however to avoid all excess of load, which would involve a serious drawback, the heating of the journals; as great velocity is itself a cause of journals heating, it must be taken into account at a high speed in the application of loads to axles fitted with small wheels. The imperfection of the *Crampton's* engine consists less, as we have seen (249) in the insufficience of the load on the hind axle with wheels of 6 ft, 89 in diameter that in the impossibility of loading it enough without excessively loading the front axle with wheels of 3 ft, 40 and journals of 0 ft, 49 in diameter.

When the loads on the rails of an engine with more than two axles, and with independent springs are tested at the end of a certain time, there are plenty of opportunities of verifying any distribution greatly different from that admitted and carried out by the adjustment of the springs. In the first place, nothing hinders the driver from modifying it; he does so sometimes inconsiderately, and unless he does it on the weighing tables, he cannot render himself an exact account of the new distribution which he substitutes for the first. The state of equilibrium may also become modified of itself; the distribution, although well adjusted at first, may gradually get more or less seriously out in consequence of the unequal wear of the bearings and of the variable alteration of the elasticity of the springs.

In the case of a great many engines, long periods pass by without the loads on their axles being tested. This is so for those which belong to a running shed not provided with weighing tables, and which in their regular work do not reach any depot possessing those appliances.

Like all the questions relating to railway stock and those especially which affect safety, the question of the unequal alteration of the springs has been, on the part of the German engineers the object of serious investigation (*). Contested by some, the reality of an unequal alteration in the elasticity, and consequently the disturbance of the distribution, is admitted by the greater number, and attributed to defective tempering. Thus, while according to the *Eastern of Bavaria*, the *Hanover*, the *Silesia* and the Mark railways etc., the alterations are without importance; the *Brunswick* rail-

(*) *Referate über die Beantwortungen der Fragen für die in September* 1865 *zu Dresden abzuhaltende Conferenz. Pages* 132 *and following. — Janecke, Hanover,* 1865.

way declares that in high speed engines with wheels free, the heavily loaded springs of the driving axle gradually lose their elasticity, which seems to arise from too heavy accidental overloading, brought on to them by the inequalities of the road; the *Thuringen* railway, that there are often differences on that score from 0tn, 75 to 1 tn, 00 between the statical loads on the two wheels of the same pair; the *West Saxony* railway, that only three days are sufficient to bring about a difference of 0 tn, 50 in the load of a wheel. The Austrian *Staats Bahn*, the *Silesia*, the *Westphalia, Saarbrücke*, *Rhein-nähe*, the *Eastern* of Prussia, etc., etc., agree with the preceding ones as to the necessity of submitting the loads to frequent testing not only on each axle, but on each wheel, and that in the interest of the tyres, of the permanent way, and especially of safety. Thus the costly establishment of weighing tables is sought to be replaced by small portable apparatus allowing each wheel to be successively weighed. M. *Ehrardt's* of which figure 2, Pl. LXXXVII gives a sufficient idea, seems to answer the purpose. But the greatest care must be taken for the successive weighing to give results nearly as exact as the simultaneous weighing. The knife edge C ought to be substituted for the rail in determining the separation, but without appreciable lifting. The flexion of the rail remains at the same time nearly constant, the pressure of the shoe p on the edge of the rail replacing and even more, that of the wheel on the head.

But the management from *Cologne* to *Minden* railway justly asserts that the use of compensating beams is the only complete guarantee against disturbances in the distribution of the weight, whatever may be the causes which tend to produce such. It does not confine itself to enunciating the principle, it puts the same into practice. All the new engines have compensating beams, and a great number of old ones have had them fitted on. But weighing is none the less, of great utility for engines in which the springs on the two sides remain independent. If, in effect, the total statical load of one axle can undergo considerable alteration, the difference of the statical loads on the two wheels of the same pair may also, and on the same grounds, take much greater proportions than one would be led to believe.

Let us cite for example two weighings of an engine with eight wheels coupled of the *Orleans* lines, done at the *Ivry* works, for the reception of an eight tabled weighing machine made by the firm of *Sangnier*. The engine was brought on the table by the front and by the end successively; it had 0 ft, 33 of water over the roof of the fire-box, and 0 tn, 25 of coal in the fire-box.

	First Weighing.				Second Weighing.		
			tons.			tons.	
Leading axle.	right hand wheel	3,76	10,26		right hand wheel	4,19	10,21
	left » »	6,50			left » »	6,01	
Second.	right » »	5,44	9,51		right » »	5,66	9,98
	left » »	4,07			left » »	4,32	
Driving.	right » »	7,24	13,85		right » »	6,73	13,33
	left » »	6,60			left » »	6,60	
Trailing.	right » »	5,52	10,54		right » »	5,17	10,66
	left » »	5,02			left » »	5,48	
			44,16				44,18

292. *Longitudinal compensating beams.* — If it is a question of establishing between the loads of two contiguous axles A, B (Pl. LXXXVII, *fig.* 3) a determined ratio r, we have, in taking the centre of moments at B, P designating the suspended weight, d the distance of the vertical from centre of gravity thereof to the point B, and p the load of A, $p = \frac{P(l'+d)}{l+l'(1+r)}$, value which ought to be comprised between the limits $\frac{Pd}{l}$, $\frac{P(l'+d)}{l+l'}$ (265).

It is always inferior to the second one whatever r may be; for it to be superior to the first, r must be at least equal to $\frac{l-d}{d}$.

To carry the required ratio into effect, it is evidently sufficient, keeping to the usual mode of suspension, to connect the two neighbouring rods by a lever mn the arms of which are in this same ratio (*fig.* 4). This arrangement is frequently met with in the single engines on the German railways. It is then between the front axle and the driving axle that the connection is established, and the ratio of the arms is fixed by the double condition of the adhesion on the one part, and of the stability on the other, that is to say, a sufficient load on the front axle.

It is very often, especially in the case of coupled wheels, equality that is required to be insured; the arms of the lever are then equal; (Pl. XXIV, b, b; Pl. XXV, b, b; Pl. XXVIII, B, B). The bearing springs may sometimes themselves act as compensating beams; in several engines of *Crampton's* system, a single spring placed above the outside longitudinal replaces the two ordinary springs (Pl. LXXXVII, *fig.* 5). If, further, the hind suspension is effected by means of a transverse spring, all the weight suspended is distributed on three points only: the middles of the three springs. The statical pressure is then invariable, not only on each axle, but also on each wheel. And this pressure is almost even independent in that case of the

inequalities of the line, which exert so great and so injurious an influence on the distribution, when all the springs are independent. The six points of support on the rails follow the irregularities of the line without their vertical oscillations reacting appreciably on the boiler. The latter is scarcely more affected, than is, by the rolling and pitching of a vessel, the compass placed in its binnacle.

But the use of the spring itself as a longitudinal compensating beam is rarely practicable. The distance apart of the axles is generally such that the dimensions of the spring would have to be excessive.

Its length and consequently its cross section can be reduced by combining it with a small double beam p, p (*fig.* 7). The frame is suspended to the spring links, and the clip of which is provided with pins which penetrate into the two flanges p, p, their length being shortened the distance between centres, and bringing the load onto the axle boxes by thrust pins.

If space is wanting between the boiler and the wheels, it is sufficient to carry the spring under the longitudinal (*fig.* 6 and *fig.* 8), suspending it by a stirrup to a small simple beam P, which on account of its slight horizontal dimensions easily finds room. Example, the compound high-speed engine of the *Orleans* lines. The single spring, placed on the flank of the frame is suspended to the parabolic solid b, b, which rests on the axle boxes (Pl. XXXV, XXXVI, and XXXVIII, *fig.* 2). The same result is arrived at by turning the spring (Pl. LXXXVII, *fig.* 9), upside down. The load being no longer concentrated on the middle of the small beam P, the latter can have a somewhat less cross section.

This arrangement is bemet with even, in Germany, applied to one single axle (*fig.* 10); it allows the spring so turned over to be lodged between the longitudinal and the axle box, in a space which would be insufficient for it, in the direct position.

Moreover, among the numerous varieties of suspension tried in Germany, there are some which can hardly be attributed to any thing but a desire to exhaust all possible combinations.

Thus, instead of lowering the joint spring, it may on the contrary be lifted up a great deal higher still than in the *Crampton* (290), as has been done on the line from *Cologne* to *Minden* (*fig.* 11). The two suspension arms are then strengthened by a strut e, passing over the boiler.

The preceding arrangements, applied to two axles, have the inconvenience of causing considerable portions of the longitudinals to overhang. This is avoided by keeping as indicated on *fig.* 4, two springs, one for each

journal, and coupling them together by a compensating beam with equal arms. On the railway from *Cologne* to *Minden* several engines have received the suspension represented by *fig.* 12: it comes to what we have just pointed out, with this difference that the rigid beam *mn*, takes the place of the intermediate spring ρ, and reciprocally. Sometimes also there is, not a change of position, but the substitution pure and simple of a spring by a rigid solid, as in one of *Vaessen's* engines (Pl. LXV); the spring of them iddle coupled wheel is replaced by a compensating beam β, β.

Connection by compensating beams has been applied to the coupled wheels of the high speed engines of the Northern of France (Pl. XXX to XXXII, *b*, *b*); in this case the two arms are unequal: 2 ft, 27 and 3 ft, 23; and the longest loads the spring of the driving wheel, which however (257) carries more weight than the hind wheel; but it is that the first receives also a part of its load from the spring ρ pressed by the inside longitudinal *l*.

The load on the rails of the hind wheels is according to the distribution of the stated weight by the builder (257) 11 tns, 505, or 8 tns, 305 suspended weight, the pair of hind wheels weighing about 3 tns, 20 (*). The load on the outside journals of the driving axle is then $8{,}305 \times \frac{0{,}692}{0{,}988} = 5$ tns, 813.

The pair of driving wheels with its enormous clamped, cranked axle and the divers pieces which it directly carries, weighing nearly 4 tns, 50, there remains to arrive at the load on the rails of 14 tns, 00, 3 tns, 657 representing the load of the inside springs.

The expression $D = \frac{pl - p''l'}{P}$ (267) gives, making $p = 10$ tns, 105, $p'' = 11$ tns, 505, $l = 8$ ft, 59, $l' = 8$ ft, 53, $P = 35$ tns, 69:

$D = 0$ ft, 033, for the distance from the vertical of the general centre of gravity to the middle axle.

With independent springs, the load on this axle could then vary between 0, and almost the whole of the suspended weight.

With the compensating beam, the distribution, without being invariable, in consequence of the independence of the inside spring, can only in that case vary between restricted limits, which are very easy to determine.

1. The minimum of the load on the rails for the pair of middle wheels corresponds to the inside springs being completely loosened.

(*) The weight on the driving wheels of the *Crampton*, 6 ft, 8 in diameter is also 3 tns, 10.

Thus, q being the load on the journals of the hind pair, its load on the rails is: $q + 3$ tns, 20.

The load on the rails of the middle pair is $0,7\,q + 4,50$ and that of the front pair $35,61 - (1,7\,q + 7,70) = 27,91 - 1,7\,q$. Putting the equilibrium of rotation, and taking B for example for the centre of the moments (Pl. LXXXVII, *fig.* 3), we find $q = 9$ tns, 72 which gives the following distribution:

Front	11,386	35 tns, 61.
Middle	11,304	
Hind	12,920	

2. The maximum of the load of the pair of middle wheels corresponds to the maximum load on the inside springs, the rest of the suspended weight being distributed over the outside journals, and in an invariable manner, by the effect of the compensating beam.

Now, the inside springs have been so constituted as only be able to support about 1 tn, 80, or 3 tns, 60 for the two.

We have then for the loads on the rails, q being always the load on the journals of the hind axle.:

Hind	$q + 3,20$
Middle	$0,7q + 3,60 + 4,50$
Front	$35,61 - (1,7q + 11,30)$.

Putting the condition of the equilibrium of rotation, we find $q = 8$ tns, 33, which gives the distribution:

Front	10,179	35 tns, 61.
Middle	13,931	
Hind	11,500	

This is exactly what the builder states. The latter corresponds then, to the maximum load of the inside springs, and consequently to the heavier load on the rails, of the pair of middle wheels.

In fact, it is preferable to come a little nearer to the preceding distribution, corresponding on the contrary to the minimum load for this pair of wheels; and this is what has been done on the Northern of France; according to M. *Wissocq* engineer of the central work shops, the mean of the weighings of several engines in work, is:

Front	10,500	35 tns, 85.
Middle	13,150	
Hind	12,200	

This mode of suspension, partly consolidated, partly independent and in which, consequently, the ratio of the loads on the two coupled axles is no longer invariable in spite of the compensating beam, is frequent enough in

high speed engines with inside cylinders. In those of the Belgian State, for example, the ratio of the arms of the outside compensating beam is also 0,7. The engines of this type constructed at the *Creusot* works (Pl. LXXVIII, *fig.* 6), present a slight variation: the compensating beam is replaced by two small cranked levers *mnp*, *qrs*, connected by a rod *b*. The loads on the two journals A and B are evidently to each other as the ratios $\frac{mn}{np}$, $\frac{rq}{rs}$ that is to say :: 0,7 : 1, *np* being equal to *rs*, and *mn* to $0{,}7 \times rq$.

When in a sixwheeled engine, it is possible to make equal the loads on the three axles, it may take place by coupling, as has often been done, the three springs two and two, by two compensating beams with equal arms (Pl. LXXXVII, *fig.* 13); but it is clear that a single one is sufficient. The equality of two of the loads completely settles in effect the distribution, so that it is sufficient to bring about the equality of the three loads, if such is possible. The application of the two compensating beams is thus an error, because it is not necessary to insure the uniformity of the distribution, when that is possible; and when, as we have said (271), the equation of condition $d = \frac{1}{3}(l - l')$ ceases to be satisfied, in consequence of a displacement of the centre of gravity, the equilibrium can only be established, with the two compensating beams, by the intervention of forces which hinder the play of the suspension; while with a single beam, a normal equilibrium is established for each position of the centre of gravity, whatever may be its variations.

It is thus that the rejection of the double beam was induced, wrongly applied to the engines with six wheels coupled of the *Geisslingen* incline (Würtemberg). The condition of equality satisfied when the engine, filled, was placed on a line almost level, ceased to be so, in consequence of the displacement of the water, on the gradient of one in 45, for which these engines were built.

Compensating beams, less used in England than in Germany, have been introduced on the *St. John's Wood* line, a branch of the Metropolitan with steep gradients; but care was taken to fix them in such a manner that they could easily be taken off, and that the thrust pins of the springs could be attached directly to the longitudinals.

The complete connection of the springs may however be warranted by the state of the lines, because it has the advantage of suppressing the overloads to which the pair of wheels independent of the two others may be found subjected in consequence of the inequalities of the line. One draw-

back is thus accepted, to escape a greater. In this way an arrangement, applied to several engines at the United States (Pl. LXXXVII, *fig.* 14), may be justified. The three journals of the same side are loaded by two common springs, to each of which the longitudinal is suspended at the one third of its length.

In France, the complete independence of the springs, is up to the present time one of the most constant characters of engines with six wheels coupled (Pl. XXXVIII to XL; Midi of France, Pl. XLI and XLII Western of France; tank engine with outside cylinders; Pl. XLVI and XLVII *Creusot* works). The solid connection for two axles is, however, we have seen, often enough used for engines with four wheels coupled, and it would be difficult to say why it is not also applied to engines with six wheels coupled. All that can be said is, that in consequence of their slow speed there is less necessity for avoiding or limiting the causes of the disturbance of the distribution.

On the other hand the application of compensating beams is almost universal in engines with eight wheels coupled. There are two on each side, three being possible only when the equation of the condition of equality of the loads (271) is satisfied; and this third compensating beam is of no use in this case, and injurious in the others, on the grounds just now pointed out.

Some times one of the compensating beams connects the first and the second axles, and the other one, the third and fourth axles, as in the engine of the *Orleans* system, Pl. XLVIII, and in those of the Northern of Spain (Pl. XLIX to LII); sometimes they are contiguous (from the second to third and from the third to the fourth axle), as in the engine of the line from *Moscow* to *Koursh* (Pl. LIII and LIV). The *Kœchlin* engine (Pl. LV to LVII) is the only exception. All the springs are independent, and wrongly so, although truly speaking the excessively reduced length of the compensating beams, in consequence of the bringing nearer of the springs, very greatly reduces their efficacity.

The engine with ten wheels of the *Orleans* lines (Pl. LVIII to LX) has also the maximum number of compensating beams, that is to say three connecting, respectively, the first and the second axle, the second and the third and the fourth and the fifth.

293. *Transverse compensating beams.* — The compensating beams are sometimes also placed transversally. They thus insure the permanent equality of the loads on the two wheels of the same axle. We have already

cited (290) examples in which this function is fulfilled by the spring itself, but the equality of the loads is not then the principal object. When that only which is desired, the lateral springs are ordinarily kept; and the two symmetrical spring rods, instead of being attached to the longitudinals, are articulated on to a transverse compensating beam (Pl. LXXXVII, *fig.* 15, B) loaded by a special support. In one of *Börsig's* types (an engine with four wheels coupled for passenger trains, Pl. XXIV), the longitudinal compensating beams *b* are placed between the hind wheels and the transverse compensating beam B in front; its axis is supported by two brackets rivetted onto the inside faces of the longitudinals. Another type also constructed by *Börsig* for the *Rhenish* railway, differs only from the preceding one by the position of the hind axle, placed, not under the inclined grate, but beyond the fire-box. The latter being greatly raised, and widened at the upper part, forms a steam dome and brings back the centre of gravity a little towards the end, allowing more load to be placed on the second pair of coupled wheels. In the engine already cited of *Schwartzkopf*, the longitudinal compensating beams are in front, and the spring works as a transverse compensating beam behind. In these, as in the others, the position is the same as if the suspended weight were placed on three points of support only, that is to say: the middle of the three compensating beams; and the distribution is then almost invariable, even in running, not only for each axle but for each wheel (292).

294. A faulty adjustment of the independent springs may be attended with very serious consequences. It is sometimes made evident by the heating of the axle boxes, which are often found too much loaded; but it may also be shown by the instability of the engine, and by the engine running off the line. There can be no doubt that this fact has had a great deal to do with many cases of running off the line, where it has been vainly sought to be explained by external causes.

The use of compensating beams has begun to extend in France; they are, however, still too much neglected there. The example of the Americans, who make so great a use thereof (except however the transverse beam), little affects us. America in spite of all, is still too far off, we trouble ourselves little as to what is done there; and we are too much disposed to admit that the peculiarities of their rolling stock entirely arise from the state of their permanent way, and are besides without interest. We should, in any case, be less indifferent to the example of Germany.

We shall return to the variations which the load of independent springs

undergoes at rest (and much more during running) under the influence of the inequalities of the line; they may reach very considerable proportions in consequence of the stiffness of the springs, and other circumstances. Every endeavour must be made to reduce them as much as possible, by attacking at the same time altogether both: cause and effect; the cause, by the solidity and careful maintenance of the line, the effect by the use of compensating beams, which greatly reduce and may even do away with the disturbance in question at the same time.

It does not differ, by the way, in principle, from that which affect simple vehicles, and it comes in addition to the special disturbances which affect engines, and which we have analysed (274 and following).

295. The manufacture of springs presents no peculiarities on which there is any occasion to dwell here. We shall limit ourselves to pointing out the use daily more general of *Bessemer's* steel, which becomes more and more *the metal par excellence* for railway purposes. Sure of themselves, being no longer subjected as before, to the uncertainties of the process, the manufacturers know how to obtain what they want, and the most of the applications to railways find in the graduated series of *Bessemer's* products, the combination of properties, suitable for each. The metal for springs naturally forms the last term, the most carbonised of the series:

Tyres	0,17 to 0,32	per cent of carbon.
Axles	0,28 to 0,35	» »
Rails	0,40 to 0,45	» »
Springs	0,45 to 0,55	» »

Examples of composition of springs. — 1. Belgian high speed engine constructed of the *Creusot* works (Pl. LXXVIII, *fig.* 6). All the springs are 2 ft, 98 in length, measured between the axis of the spring rods, and are formed of plates of 0 ft, 33 in breadth, and in 0 in, 39 thickness.

Number of plates	front and back springs	15
	outside middle springs	13
	inside » »	10

2. Common spring suspended to a compensating beam, of the eightwheeled engine, of which the four intermediate are coupled, of the Russian railways (Pl. LXXVIII, *figs.* 14 and 15); chord measured between the spring rods, 3 ft, 94; thickness of the plates 0 in,59, number 14. Flexibility per ton 0 in, 24.

3. Engine with eight wheels coupled of the Northern of Spain (Pl. XLIX to LI). The eight springs are formed of eleven plates 0 ft, 29 in breadth, and 0 in, 47 in thickness. Length between the rods 2 ft, 95.

It would be superfluous to multiply these examples.

§ III. — **Axle boxes and bearings.**

296. *Axle boxes.* — Axle boxes of waggons are always for outside frames. Those of engines are as much for outside frames, as for inside ones, and often as we have seen, the two frames are united in the same engine.

Axle boxes for engines have not exercised the talents of inventors, in the same degree as those for waggons. That is quite natural; an engine is never left to itself; its axle boxes participate in the incessant inspection of which it is the object throughout all its machinery; on account of these quite special conditions they work well, and there would be nothing gained by modifying them. Oil is always employed for lubricating the journals of engines, but the boxes have always an upper reservoir. The engine driver's hand being constantly present, renders unnecessary, in effect, all the arrangements for the purpose of insuring good lubrication in the axle boxes which have to run a long time unattended to.

Cast iron was at first exclusively employed for the axle boxes of engines, as well as for those of waggons. But for several years wrought iron (and also recently *Bessemer* steel), has taken the places of cast iron for the axle boxes of engines with inside frames. As to axle boxes with outside frames, closed in front, the complication of their form renders moulding necessary; they are thus of cast iron and often of brass.

The manufacture of wrought iron axle boxes is simple enough; it consists of the following operations; 1. the partial drawing out of a block of convenient dimensions A (Pl. LXXXVII, *fig.* 21); 2. division of the piece B (*fig.* 22) along *m*, *n*; 3. shaping under the die of the necessary grooves and projections; 4. application along the two faces *m*, *m*, and welding (*fig.* 23); 5. shaping out of the hollows for the oil reservoir, and planing.

297. *Bearings.* — Bronze is used almost solely in France. The alloys, termed antifriction metals (78), applied to waggons are a good deal used also in England and in Germany, for engine bearings, but ordinarily in the state of a simple lining, a very small fraction of an inch in thickness.

The brass of the bearings is very irregularly utilised. The instruction No 82 of the locomotive department of the *Méditerranée* line has the following (art. 14):

“ The same as for the journals of engine and tender axles, the admissible reduction

of thickness of the bearings depends on the sum of the conditions of the engine and of the tender, and no rule can be fixed in this respect. "

§ IV. — Axles.

298. *Rarity of accidents caused by engine axles.* —The breakages of axles take a prominent place in railway accidents. It is the most frequent cause of trains running off the line, the results of which often harmless, are sometimes disastrous. As we have said farther back (84) breakages of axles of passenger carraiges, and waggons at *high speeds* are very rare; and the accidents are caused by the giving way of the axles at *low speed* waggons (*), included in passenger trains. These breakages take place in the nave (85); and ninety nine times out of a hundred, the existence of an old crack is found running nearly from the circumference to the centre, and occupying sometimes the half or even the two thirds of the section. A real guarantee was thought to be in the reduction of the load of low speed waggons, when coupled on to fast passenger trains; but as we have said (88) what is the use of this reduction in the case (as is of course unknown) of an axle already affected by cracks inside the nave, of which the complete and speedy fracture is inevitable? All that it can do is to put off the result for a short time, and there are as many chances that putting it off will aggravate its consequences as reduce them. Besides, when a goods waggon is loaded in a station, it is very often not known to what train it will be coupled, so that, to do away with all risk, the reduction of the load ought to be absolute, without exception.

As long as the position remains what it is; so long will it be impossible to discover by the minute inspection of an axle, if it be sound or not; and as long as the probability of the existence of cracks hidden by the boss, continues as strong as it is for certain types of axles either too weak or badly designed, there will be no serious guarantee for the safety of passengers, excepting by a suitable limitation of the speed of trains which take with passengers low speed waggons together suspected with justice of having axles with fractures more or less advanced. The speed, as will be understood, is doubly objectionable; it may not only produce the fracture of a cracked axle, but also and especially, it aggravates almost

(*) The returns printed annually by the companies divide their stock into two great classes. 1. *Carriages and waggons for fast trains.* 2. *Waggons for low speed trains.* See for example the classification of the *Méditerranée*, 1st January 1872. in-8° (pages 23, 27, 35, 37, 49).

inevitably, the effects of this fracture. In the Additions (*) will be found some new facts, and observations touching this important subject, the character of which is not exclusively scientific and technical.

As to the accidents caused by the breakages of engine axles, they are very rare, and that on three grounds :

1. The small number of engine axles, relatively to the number of waggon axles comprised in the same train;

2. The chances of fractures while in work, a great deal less for the straight axles of engines than for the axles of low speed waggons;

3. The almost certain absence of serious consequences, if this fracture (frequent only in the case of cranked axles) occurs.

The breakages while in work of straight engine axles, are very rare in consequence of their great calibre, the care taken in their manufacture, and of the constant examination of them by the drivers, and of the shed staff who often succeed in discovering cracks in time. There are plenty of hidden parts however, in many driving axles : these are portions on which eccentric sheaves are keyed; which is a further reason for bringing valve motions outside the wheels.

At the same time, it must not be imagined that, even with the axle exposed, the cracks, if they exist, cannot escape an experienced eye. They are sometimes quite invisible, and only become manifest by the application of heat.

As to the probable harmlessness of the fracture, when it takes place, it arises mainly from the fact that the driver, becoming immediately aware of it, slackens speed and stops. If he does not do so, as sometimes happens, it is because the running of the engine hardly feels the breakage.

This is what takes place in the case of a fracture towards the middle of a cranked axle carried by longitudinals placed between the cranks; the two portions continue to work, each by itself.

In such case, the driver has been known to continue his journey without hindrance; warned only by the irregularity of the blast due to the independence of the two engines, he believed he had to do with something quite different to the fracture of a driving axle, and found on examining his engine, the two fractured surfaces abraded by their mutual friction.

299. The determination of the dimensions of engine axles, especially cranked ones, is up to the present time, purely empirical. A great excess

(*) See at the end of the volume.

of strength is endeavoured to be given to them, as is shown by the single fact fothe absence of fractures. Pl. LXXXVII, gives 1st. *figs.* 31 and 32, the dimensions of the driving axle, and the coupled axle, in wrought iron, of an engine of the Upper Italian railway, with outside cylinders and inside frames; 2nd. *fig.* 33, the outline and figured dimensions of a driving axle, of *Bessemer* cast-steel, made at *Seraing*, for an engine with inside cylinders and coupled wheels.

The journals whether inside or outside, participate in this excess of diameter which prudence dictates, and great length, is at the same time given to them so as to have large bearing surfaces and good lubrication. So the wear of these journals is ordinarily very slow.

" Axles fail ordinarily by serious cracks or fractures produced either by their normal work, or by exceptional shocks. The normal wear of the axles of engines and tenders is little appreciable ; the admissible reduction of their diameter depends on the conditions taken altogether of the engine or of the tender. *Nothing can be fixed previously with respect to the wear of axles.*"

Thus is expressed the service instruction (No 82) of the locomotive department of the *Méditerranée* system, according to the terms of which the carriage and waggon axles are withdrawn when " their work or turning down has lost journals more than 6 per cent of their primitive diameter. " They are not however as badly off as would seem from this declaration lessness powers. If as we have seen (84), the department has given up for a long time, and rightly, keeping of the distances registers, run by waggon axles, this measure, is always obligatory and carried for engine and tender axles ; it furnishes or rather it could furnish useful particulars. We will cite farther on a certain number of examples of distances run. In fact, a guarantee of a stated distance run is always entered in the conditions of purchase of engine and tender axles.

300. *Manufacture of axles.* — The manufacture of straight axles in wrought iron, is nothing different from the forging of other large pieces.

The shingler and the steam hammer perform their usual part in it, and the process is too well known for us to require to dwell on it. As to cranked axles, different methods have been tried, but the one which is generally returned to, does not differ from the process applied to cast steel axles, and which will be presently pointed out.

It will be sufficient, as an example of other processes, to mention that applied by MM. *Petin* and *Gaudet*. One of its features is the employment

of an enormous packet giving as many as six axles. The weight of a rough axle being 1 tn,20 (or 7 tns,20 for the six), the packet formed of cuttings and scraps, weighs 10 tns,50; loss 3 tns,30. Starting with a packet intended to produce several pieces of relatively slight dimensions, is in accordance with a power of tools, established with the view of forged pieces of exceptional dimensions; it allows appliances to be utilised for ordinary pieces, which would otherwise very often remain idle. But the quality of the products does not always agree with this practice; whatever may be the power of the appliances, a piece of too large dimensions is not thoroughly welded and worked.

However the packet is drawn out into a bar of 0,48 feet in diameter, and afterwards alternately flattened in perpendicular planes (Pl. LXXXVII, *fig.* 24); the bar is then cut into six lengths of the form indicated by figure 25. Five heats are necessary to arrive at that. The shaping of the hollow of the cranks by the slotting machine, the drawing out of the straight parts: bodies and ends, require seven fresh heatings; the crud axle is thus got; it is handed over to the smith's forges and finished in thirteen heats. There are then, twenty five altogether.

The mean running of cranked axles is greatly inferior to that of straight ones. The fracture often takes place in the crank arms, as is easy to conceive. By increasing the dimensions of those parts however, conditions of equality of resistance have been so nearly attained that the fracture occurs often enough in the body itself.

The application of the load on both sides of the wheels, is evidently a positive guarantee, although it has been found fault with even in this respect by some engineers, among others by Mr *D.-K. Clark*, who regards (*) this distribution as " a radical error and as the real cause of the relative weakness of cranked axles." He limits himself besides, to this remarkable statement, which experience has condemned.

301. *Compound axles.* — The complicated form of the cranked axle naturally led to the one piece being rejected, and to try to build one up of separate pieces of easier execution and allowing of partial replacements. In *Schivre's* axle, tried on the Eastern of France, the two crank pins were separate; it was thus formed of five pieces altogether. But in spite of the dowels being put on whilst hot, they got rapidly loose. An analogous axle of Mr *Dyer Williams* was composed solely of straight bars,

(*) *Railway Machinery*, page 237.

socketted together whilst hot, and consequently nine in number; it was naturally attended with still less success.

302. *Axles with simple cranks.* — There is a means of simplifying the form even of the cranked axle, but only in the case of engines with outside frames; that is, to utilise the boss of the wheel, as an outside arm. This axle which bears the name of *Martin's* axle, has received several applications on the Western of France railway, among others in the high speed engine with four wheels coupled (Pl. XXXIII and XXXIV). *Figs.* 3 and 5 of Pl. XXXIII indicate the details of this arrangement; each of the arms *m* of the crank leaves the body of the axle by a proper inflection and is let into the boss, which is there thickened on the inside (*fig.* 4) and thus offers a large surface for keying on of the axle, and, as well as for the inside and central appendice forming the journal in the coupling crank. This axle is far from new. It existed in engines constructed in 1837 by *Baldwin* (*). Mr *Schellhammer* remarked it in a voyage to the United States, and on his form that M. *Beugniot* designed in 1842, the engine represented *figs.* 6 to 8 of Pl. LXXV.

303. *Clamping the cranks.* — A very efficient means of prolonging the durability of cranked axles, even when some cracks have already shown, consists in binding each of the four of the crank arms with clamps put on hot. When this clamping is done while the engine is at work, and if it be desired to avoid taking off of the wheels, the clamp cannot be in one continuous piece, but has to be an open link tightened up by a strong key. Now-a-days the binding is often applied at the very first. The new high speed engine of the Northern of France is in this case.

304. *Cast-steel axles.* — The application of cast-steel for engine axles is already old, even in France. It has made very little progress there, which arises from the indifferent success of the first trials, made however on crucible cast-steel, which was little inviting, apart from the question of price, for the adoption of *Bessemer* steel. On the Northern of France of six cranked axles in *Krupp's* crucible steel, one broke after 25.400 miles, one already showed cracks and had to be clamped at the end of 26.000 miles.

Now-a-days, however in England, Belgium and Italy, in a great part of Germany, *Bessemer* steel axles, inspire an amount of confidence which they justify in effect. Mr *Ramsbottom* has added to the *Crewe* works

(*) *Recent practice in the locomotive engine — American locomotive,* by *Zerah Colburn.*

a *Bessemer*, where are manufactured all the products which the railway makes use of, and notably cranked axles. The South Austrian railway, which has greatly developed the manufacture of *Bessemer* steel at its works at *Grätz*, has applied it for a certain number of engine axles, and to a great many tender axles (a trial which is often rough enough in consequence of the frequent application of brakes), to *Halls* cranks, etc. The results are satisfactory.

All builders agree however to know that the metal ought to be soft, that is to say at a low degree of carburation, about 0,3 per cent (295). Under this proportion, the wear of the journals would become appreciable; but at this degree, which is a guarantee against the brittle nature of the metal, several engineers state that they have also found that the wear of the bearings and the consumption of oil, are less than with iron.

Amongst the establishments which devote themselves to the manufacture of cranked axles of *Bessemer* steel, one of the most important is that of *Seraing* (Belgium). It will not be without interest to enumerate rapidly the series of operations by which the ingot is brought to the form of the crude cranked axle. The ingot ought to weigh almost double that of the finished axle, the total loss, as much as for the reheating and hammering as for the mechanical operations, being near 50 per cent. Thus for an axle weighing finished 1 tn,20 the ingot weighs at least 2 tns,00. 1. Heated to a white heat, it is transformed under steam hammer into a parallelopiped, *capable*, with an excess of about 15 tons an inch in all directions, of giving the rough axle, if the two cranks were in the same plane; 2. Second heating, and slotting out under the steam hammer, of the three blocks B, B′, B″ (Pl. LXXXVII, *fig.* 26). — In the same heat punching and always under the steam hammer, the two holes T, T, for beginning the slotting out cold, the hollow of the cranks.

3 and 4. Third and fourth heats, these only partial, for the shaping out, and rounding off the ends R, R:

5. Turning the two cranks at 90 degrees. It is brought to the body only white heat; then the one of the cranks being flat on the anvil, held down by the hammer of 15 tons, and the other end suspended to the crane, the second crank is taken by a lever on which four men act, who, in a few minutes, give the body the necessary twist.

6. A sixth and last heat serves to correct the slight faults produced by the twisting to disappear.

The rest is only a matter of turning down in the lathe.

305. *Distances run by broken wrought iron axles.* 1. *Straight axles.* — The return of distances run by straight axles, broken on the *Méditerranée*

system, indicates figures variable between extremely wide limits. Let us cite some of them:

	Miles.	
1. Considerable mileage..	324.447	(wheels free, driving axle.)
	320.055	— —
	288.000	— —
	279.700	— —
	253.010	— —
2. Very small mileage....	20.090	(front).
	19.370	(driving).
	18.430	(six wheels coupled).
	16.210	(four wheels).
	15.570	(driving axle).
	9.900	(six wheels coupled).
	8.370	— —
	6.180	(wheels free, leading axle).
	2.630	— —
	970	— —

On the Eastern of France the mean run of straight driving axles broken, was at the end of 1867 : 169.486 miles.

2. *Cranked axles.* — On the same system 449 cranked axles broken, up to the 31st of December 1867 ran a mean distance of 91.800 miles.

Out of this number 48 breakages took place in 1867, and the mean run of these 48 axles rose to 105.928 miles.

These last figures are far from presenting differences as considerable as the distances run of straight axles already cited higher up. Thus the two lowest figures are 59.257 miles, and 61.758 miles, and the two highest figures are 210.548 miles and 257.618 miles. On the Northern of France the maximum was 225.060 miles.

We do not find figures nearly as considerable as these three last, in the distances run of cranked axles on the *Méditerranée* system. Here are several examples of there latter years:

185.620	132.980	122.220	86.990	40.220
173.440	132.810	103.030	82.800	38.900
161.270	129.720	99.800	79.060	35.000
150.470	128.180	95.480	70.740	31.470
138.600	127.300	87.570	51.650	29.920

However, a cranked axle (marked R, No 1664, *Petin* and *Gaudet*) broken in working on the 2nd of August 1872 in the station of *Saincaize*, is indicated as having run 227.689 miles, but it was a shunting engine, and consequently a fictive distance made up from the length of time the engine was in work.

It is moreover certain, and easy to understand that the distance run by

shunting engine axles, is relatively very considerable, in consequence of the shortness of the journeys, the slow speed, and frequently running without any load.

306. *Distances run by axles still in service.* — The distances run of axles are only totalised when they are replaced, and breakage is almost the sole cause of replacement. We see only written down in the different returns, the run of broken or cracked axles, and these figures may be absolutely improper to give an idea however little exact, of the degree of, mean or maximum, utilisation of the axles. There may be, and there very probably are, among axles in service, some in which the distance run exceeds and perhaps by far that of the broken axles which have lasted longest.

Thus as we have already said (84) fracture is the consequence not of the molecural alteration of the metal, but of some fault in the manufacture. The axles which are exempt therefrom, and which have not had to undergo through any accidental cause, such as running off the line, a collision, excessive strains, why then should they not run very long distances?

It was interest to clear up this point. I thus had drawn up, failing the ten highest distances run, which would have been better, but which would have taken longer to work out, ten of the most considerable distances run of the axles in service under two series of engines of the *Méditerranée* systems. Here are the figures:

1° *Straight driving axles.*

MARKS and numbers of the axles.	SUPPLIED BY.	SERIES of the engines.	DISTANCES run up to 30th April 1872.
			Miles.
B.—372	Petin and Gaudet	101 to 145 (This is the modified type represented by Pls. XXVIII and XXIX.)	414.940
364	do		399.770
378	do		389.670
352	do		389.370
351	do		383.780
377	do		383.770
344	do		369.880
342	do		368.090
362	do		354.410
350	do		347.880

The lowest of these figures is thus higher than the highest distance run (321.873) of the broken axles. No driving axle of the series 101-145 has broken up to this day.

2° *Driving axles cranked.*

MARKS and numbers of the axles.	SUPPLIED BY.	SERIES of the engines.	DISTANCES run up to 30th April 1872.
			Miles.
E.—585	Petin and Gaudet	301 to 312 (Engines with leading wheels coupled and trailing axle behind fire-box.)	110.150
391	Monck-Bridge works		72.613
389	Bowling works		64.000
397	do		59.625
398	Russery and Lacombe		57.185
595	Bowling works		55.900
967	Petin and Gaudet		47.580
583	do		44.000
1823	do		41.250
390	do		21.715

Here, the most of the axles are too soon in place and have in consequence only short distances run, without interest. We must therefore go to the distances of breakages. Since the origin, thirty three breakages have taken place in this series of twelve engines, and their respective distances run were:

Distances run by the thirty-three cranked axles broken under the engines of the series 301-312.

MARKS and numbers of the axles.	SUPPLIED BY.	DISTANCE RUN.
E.		Miles.
390	Petin and Gaudet	285.250
583	*Idem*	174.970
398	*Idem*	152.760
397	*Idem*	144.610
393	*Idem*	146.850
391	*Idem*	142.100
585	*Idem*	137.825
590	*Idem*	135.835
399	*Idem*	135.140
583	*Idem*	123.875
595	Laubenière	130.205
396	Petin and Gaudet	126.670
396	*Idem*	123.575
1823	*Idem*	114.450
967	*Idem*	112.590
394	Bowlings (works)	102.175
393	*Idem*	95.460
590	Petin and Gaudet	95.265
390	Bowling (works)	88.290
399	*Idem*	87.420
967	*Idem*	87.155
393	Petin and Gaudet	86.065
1820	*Idem*	79.400
399	*Idem* a	77.345
1823	Bowling (works)	71.945
590	Russery-Lacombe	70.488
590	Monck-Bridge (works)	69 514
595	Petin and Gaudet	69.353
398	Russery-Lacombe	65.470
1820	Bowling (works)	64.809
396	*Idem*	57.391
595	*Idem*	42.420
583	Laubenière	36.102

The distance run guaranteed by the supplier is ordinarily 93.000 miles, either for steel (*Seraing*) or for certain superior sorts of irons (*Bowling*).

307. *Tender axles*. — The very frequent action of brakes is often a cause of strain and breakage of tender axles.

That depends, however, on the arrangement of the brakes; for example, those which act only on a single wheel and skid the other by the intermedium of the axle, act on the latter in quite a different manner, to brakes acting on the two wheels T, which is very rare, on both sides of them and especially of the *Graffenstaden* fourwheeled engine (Pl. LXXXIII, *figs*. 1 and 2).

The mean run of the tender axles broken in 1867, on the Eastern of France was 259.482 miles. On the 1st of September of the same year, the distances effected by thirteen axles placed under so many tenders were recorded. These varied from 327,452 miles to 414.434 miles. One of the axles of the small tenders withdrawn from work in 1867, in consequence of the smallness of their journals, ran 434.930 miles. Perhaps it might still have run a long time.

Statement of ten of the highest distances run by tender axles of each of the series 101-145 *and* 301-312, *Méditerranée*.

NUMBERS of the axles.	SUPPLIED BY.	SERIES of the engines.	DISTANCE RUN up to the 20th April 1872.
			Miles.
194	Petin et Gaudet		402.764
168	*Idem*		386.816
178	?		381.302
176	Petin et Gaudet		374.178
165	?		369.210
184	Petin et Gaudet	101 to 145	363.923
169	?		362.399
358	Petin et Gaudet		360.425
202	Works of Vierzon		359.138
173	?		358.144
696	Petin et Gaudet		395.507
479	*Idem*		327.619
478	*Idem*		324.824
474	*Idemt*		321.197
514	*Idem*		316.132
477	?	301 to 312	311.327
497	Petin et Gaudet		300.556
496	*Idem*		296.974
473	*Idem*		295.088
475	*Idem*		292.336

No more breakages have taken place under the tenders of these two series. It is probable that these distances which are already all consider-

able, as we see, may reach for a certain number of these axles, higher figures still.

I regret not being able to push further this verification of maximum distances run, as it would be so useful and so instructive, if the figures of the sources of supply and of the conditions of manufacture, were compared. However what precedes will no doubt be sufficient to call the attention of the companies to this point.

§ V. — Wheels.

308. The wheels of engines differ from waggon wheels by their diameter, always greater, and often a great deal more; by their more solid constitution, in accordance with the considerable load which they support; and, if required, by the existence of a crank or cranks and a counterweight (278 and following). For a long time the *centre* was formed as it is often still (104) in waggons, of cast iron spokes mandrilled and fixed in a cast iron boss. This method is given up. Although formed of T iron, the spokes gave too much, and the tyre got loose. On the other hand the heavy cast iron bosses were bound to disappear as soon as a reduction of weight became absolutely indispensable. Engine wheels are thus of wrought iron, and sometimes of steel. It is only in the United States, that cast iron is prefered for engine wheels, as well as for waggon wheels as we have seen (108).

If we seek what is special in the conditions to which the driving wheel is subjected, we immediately find that it acts at the same time as a carrying wheel, and as a pulley with a cord wound round it with a tension equal to the effort of traction, or the tangentical reaction of the rails on the tyre. Each of the spokes is then a solid compressed along its axis, solidly fixed at one end to the boss, and solicited at the free end by a normal force, equal to the effort of traction divised by the number of spokes; which would lead these to be enlarged from the rim to the boss, in the plane of the wheel. This enlargement always exists in fact. As to that which the reactions of the rails on the tyres require, it is common to all wheels (103) and naturally more prominent in engine wheels.

309. *Manufacture.* — 1° *Arbel's process.* — The process of manufacturing waggon wheels of wrought iron, briefly indicated in No 105, is applied also to engine wheels. In France now-a-days, wheels manufactured by MM. *Arbel's* and *Deflassieux's* process, are generally preferred; it is really moulding

by means of a die iron softened very uniformly by a high temperature. The whole wheel is formed of the same iron. It ought to be very fibrous, the operation tends to make it pass into a granular state. To make the rim, a straight bar is curved round to a welding heat, seized by a sort of large clamp with a set screw, and brought in a smith's forge. The diameter perpendicular to the welding faces, being unable to expand, these faces are greatly compressed, and welded; very simple forging does the rest. It is process already indicated for welding tyres at *Allevard* (120).

The rim cooled passes on to the slotting machine, which prepares the places for the ends of the spokes. These, cut to length are heated, drawn out at one end, the one which has to go into the boss, and shaped at the other in a mould, which brings out an enlargement and afterwards a projection corresponding to the notch in the rim. A packet is then made containing: 1. stamped out plate, which will form half the boss; 2. the spokes fixed by one end into the notches of this plate; 3. the rim, the mortice-holes in which receive the exterior ends of the spokes; 4. a second plate similar to the first, placed thereon, but without contact; wrought iron distance pieces, isolate them, so that the system thoroughly permits the gases of the furnace to permeate it, and rapid heating, in spite of the greater concentration of the metal at that part. There are added if required, bars of iron to form the crank and the counterweight (282). The whole is consolidated by binding with wire, and the packet taken hold of by a great pair of tongs with circular legs, is introduced by a side door into the reheating furnace.

For a long time the counterweights were put on separately, and fixed by bolts (Pl. XXV and XXVI, KK); but the shocks and vibrations loosened the fastenings, and the counterweights frequently dropt off. The suppression of this drawback is not one of the least advantages of the *Arbel's* process.

The construction of the reheating furnace was the delicate part of the operation. A great deal of trying was required in order to get all the portions of the packet, weighing often as much as 0 ton,5 nearly at the same time, to the same temperature in spite of the differences of calibre. The spokes would burn if they reached, sooner the thicker boss, the white heat necessary for welding. The furnaces are arranged in such a manner as to concentrate the heat principally on the centre of the hearth, occupied by the boss.

In consequence of a small excess of length given designedly to the spokes, the wheel in the rough which constitutes the packet, has a slight dish,

so that flattening it under the hammer tightens very greatly. The heating lasts from one hour to one hour and a half according to the dimensions of the wheel; the packet passes then to the steam hammer. The anvil and the hammer have both a movable die variable according to the type of wheel. Brought together, these two moulds, the exact superposition of which is insured by guides, leaving between them the form of the wheel, with a little increase of course in consequence of the heat that it possesses at the end of the hammering. In three or four blows it is thus moulded and welded. To insure powerful compression of the metal, there must evidently be an excess in the packet. Under this first volley of blows the two moulds do not, then, come nearly into contact, a part of the excess of metal squeezing out under the form of thick seams. These are roughly cut off, and the wheel, reheated, is placed turned over in the lower mould, and receives a new volley, followed by a cleaning off the seams, this time very much thinner. When required, the same series of operations is done once more. After the cooling, which ought to be slowly done, then comes the verification of the welding of the spokes and of the rim; an operation which consists in reheating them one by one, and to insure by the continuity of the shade of color, that the continuity of the metal is quite complete. Nothing then remains but to clean off the wheel, removing the seams completely by means of the chisel and file. All that requires a considerable amount of hand work; but the whole process is not the less economical, and no other perhaps gives such perfect welding. The steam hammer for large driving wheels, weighs with the upper die, 25 tons.

At *Fives-Lille*, the boss is obtained by hammering a packet formed of a sort of trundle of iron plate, the openings of which receive the ends of the spokes, and which is afterwards filled with metal scrap.

2. *Seraing Process.* — The method followed at *Seraing* is less expeditious; it has not the character of boldness that distinguishes M. *Arbel's*, but as it equally gives very good results, it is well to briefly describe it. It consists of:

1. Roughing out of the boss;
2. Shaping the spokes;
3. Welding the spokes and the boss;
4. Shapening and morticing the rim;
5. Welding the spokes and the rim.

1. *Nave.* — This is drawn from a packet, nearly cubical, of bars of No 4 and weighing for example 280 lbs for a boss of 208 lbs. This packet is heated

and brought under the 5 ton steam hammer to the cylindrical form; this cylinder P the height of which exceeds that of the boss by about 4 inches, is heated to a white heat and placed vertically on the anvil, surrounded by a mould MM (Pl. LXXXVII, *fig.* 27) in two parts, tightened by a cast iron collar C, C, slightly conical for getting it off. As the centres of the axes of the mould M, M, and of the cylinder P have to coincide, the first is put on a ring AA, the thickness of which is equal to the half excess of the height of the second. Under the steam hammer, striking successively the two ends of the piece, the metal forming the excess of height is driven in and fills the two empty circular spaces *aa*, *aa*. The boss is punched by the machine at the same heat.

2. *Spokes.* — These are cut out, an excess of metal being left, so as to form the thickenings towards the nave and rim, and they receive their definite form under the die (*fig.* 29).

3. *Welding the nave and the spokes.* — The spokes are put in their places, their enlarged portions *rr* are let into the throat *gg* (*fig.* 28) of the boss, and the whole is tightened by a large collar in two parts like eccentric clips; one of them carries an appendage with counterweight, which brings back the centre of gravity on to the throat taken by the chain of the crane. The central part of this sort of star is heated in a particular furnace alone where it is exposed to the action of the flame; a small wall of earth raised in the spaces of the spokes keeping the rest from the action of the heat. As the collar opposes the expansion of the system, there results, between the faces of the boss and of the spokes, brought to a high temperature, a very considerable pressure which perfectly prepares the welding; this is completed by three or four blows of the steam hammer, which terminate at the same time the shaping of the boss (and of the crank if there is one) as well as of the inside ends of the spokes. The collar now useless is removed, and the spokes cleaned off.

4. *Rim.* — The rim is a ring obtained by the same process, as the wrought iron or puddled steel tyres, called: weldless. A packet of No 4 iron, is rolled out into a flat bar, and then wound round a core, which is slightly conical, so as to facilitate taking off the helix. The annular packet is reheated, welded together in a mould, under the 15 ton hammer, reheated again, and twice rolled (reducing and finishing) in the circular rolling mill by hydraulic pressure. The notches which receive the shaped out ends of the spokes are then made on the inside face by the plotting machine.

5. *Welding the spokes and the tyre.* — The star lowered horizontally by the crane, slips down into the rim, the ends of the spokes lodging in the

notches. For some, the joint is tight, and wants a little help with the hammer; for others, the joint is on the contrary a little loose, and small pieces of sheet iron have to be inserted.

The welds are done one by one; to facilitate this operation, the wheel is manœuvred by means of a lever with a clip, which takes it at its centre by means of a bolt, round which it is made to turn. Each welding consists of two operations; 1. welding by hand, with the addition of a little iron; 2. hammering by a steam hammer in a cast iron swage.

310. *Wheels with discs.* — Wheels with full discs, are little used for engines; they have already ever been made of any thing but cast-steel, and then they are in one single piece, without separate tyre. It is only when the rim and the flange are too thin by wear and turning down that the flange is cut off and an ordinary tyre applied. They have been tried in Germany and in England, but are little used in those countries. The Hanover railway, and the line from *Cologne* to *Minden* have however several hundred pairs of them under their goods engines.

Full wheels have only one advantage, and that only applies to the wheels behind the fire-box and to tender wheels; that is the fragments of fuel which fall from the fire-box and rebound from the ground are no longer liable to be thrown up on to the train, as they are by spokes. The full disc has besides the drawback, which by the way, like the advantage, is not absolute: of more or less hindering the view and access to certain parts of the engine; the objection does not thus apply to engines all the mechanism of which is outside, like the locomotive with eight wheels coupled of the Belgian State, for example; it has thus received full wheels (Pl. LXXIV, *fig.* 2).

311. *Cast iron wheels.* — In the *United States* the use of cast iron is general, for engine wheels as well as for waggon wheels (108). The small wheels of bogies are cast in a chill box; the driving wheels have generally a separate tyre, and very often of *Krupp's* cast-steel. Mr *William Adams* had a set of wheels brought from the *United States* to *London* which he applied to the bogie of one of his heaviest engines. After long service, these wheels did not present any trace of wear. However, this example which besides is insufficient, has been unable to get over the distrust which cast-iron always inspires in Europe.

In Germany, the application of *Gruson's* cast iron for locomotive wheels appears to be limited to some shunting engines. There were formerly seen

on the Austrian railways several of *Norris's* engines with wheels entirely of cast iron without separate tyres. At the end of seven years running, the wear was almost nothing, and these wheels never broke.

312. *Fly wheels.* — A well known builder, M. *Kessler*, applied cast iron to driving wheels with quite a special object. This was make regular fly-wheels of them and give them a great moment of inertia. They were of cast iron, all in one piece. The rim and the spokes having the same dimensions, very strong, and the dimensions of the boss being relatively slight, the cooling was effected almost uniformly and consequently without inside tension. In the engines of the Hessian railway, weighing empty 20 tons, the pair of wheels of 5 ft, 25 weighed 3 tns, 10, that is to say as much as *Crampton's* wheel of 6 ft, 89. These engines ran, as I verified, very regularly and very smoothly. However a useless dead weight, always a bad thing, is always worse still, when not suspended on springs.

§ VI. — Tyres.

313. *Profile of the tyres.* — Almost all that has been said (111, and following) on the waggon tyres applies to the tyres of engines and tenders. There remains therefore little for us to say on this subject.

We have already remarked (112), that on a great number of lines, the profile of the tyres is the same for all vehicles. On some other lines, the tyres of engines set apart especially for sections with sharp curves, have a greater conicity than those of the rolling-stock. Sometimes also the thickness and the breadth of the engine tyres are slightly greater than those of waggon tyres, but the increase of width arises almost solely the flange of the first being strengthened.

The two profiles newly adopted on the Belgian State railway, and represented by *figs.* 34 and 35, Pl. LXXXVII are in this case.

The tyres of the driving wheels and in general of the intermediate wheels pretty often present two peculiarities: the absence of flanges, and its immediate consequence; the absence of conicity. If we consider an engine with three axles invariably fixed by their guard plates, successively on a straight line and on a curve (Pl. LXXXVII, *fig.* 36) we shall see that in the second position, the inside rail tends to press up against the flange of the middle wheel, and that at the same time the conicity would act in the contrary way, the outside wheel rolling on a smaller radius, and the inside wheel on a greater

radius than the mean radius. But the suppression of the flanges is a source of danger for engines which do not run very slow, and the suppression of the conicity is only a palliative. Consequently these two features disappear more and more: the tyres of the intermediate wheels differ from the others at the very most by their thinner flanges, the conicity remaining and acting in the required direction, on account of the play given to the axles in the direction of their length, a point which we shall soon come to.

A compound profile has sometimes been given to tyres without flanges; cylindrical for about the half their breadth (inside) and conical on the other half (*fig.* 37, this is a form applied on the Eastern of France). It is evident that nothing warrants it; with disappearance of the flange, which supposes the axle fixed lengthways, the cylindrical form is the logical one.

On the *Méditerranée* system, all the tyres, either of iron or of steel, are when new and turned down, 2 ins,16 in thickness at the middle of the rolling surface. The following are considered as beyond service:

1. Tyres less than 1 in,57 in thickness, and which present any apparent default of a nature to interfere with their working;

2. Those which present after turning down thicknesses below 1 in,38 for engines and 1 in,18 for tenders (we have seen (112) that for waggons the limit is 0 in,98).

These limits are generally only reached, in the case of tyres remaining on the same wheels, in single engines. In engines with coupled wheels, if, when one or two tyres fail, the others are reduced to 1 in,57 in thickness, for example, it would be better to replace the entire set, than to put on two new tyres (2 ins,16) which would have to be immediately reduced in the lathe to 1 in,57. Besides the tyres taken off are kept, to be put with others of the same thickness, and so form a complete set of wheels.

On lines with sharp curves, the flanges of the front wheels wear rapidly, especially if the axle has no transverse play in the frame; their profile alters in proportion to the radius, to the tilt, and to the speed, to the distance apart of the end axles, and to the radius of the wheels themselves; the flange grinding the outer rail, at an angle the more open, all else equal, the greater this radius.

Every pair of wheels the flanges of which are reduced by one third must be withdrawn from service and the normal profile of the tyre re-established as much as possible, by taking advantage of its thickness.

314. *Nature of the metal.* — *Low-Moor* tyres were long considered

as the *nec plus ultra;* but those of the steely irons of *Niederbronn* and *Allevard* have been able to stand comparison and often with advantage.

Puddled steel has sometimes done very excellent work; but it is rarely homogeneous, and the less so the greater the diameter; a large piece is never throughout equally refined. Homogeneity is only found in materials which have been cast, superior at the same time in this respect, by the absence of welding. But it must be exempt also from a vice of an analogous nature, flaws.

The tyres called weldless, because they are not welded transversally, but are formed of a bar wound round spirally, are subject by that very fact to perilous injury. *Fig.* 30 of Pl. LXXXVII represents the way in which gets crushed a tyre of this kind manufactured by MM. *Petin* and *Gaudet*. In consequence of the crack and of the crushing of the rolling surface, the flange was thrown over 0 in,79 towards the inside of the line.

The employment of cast-steel is almost general now-a-days for engines with heavily loaded wheels. It ought however to inspire a certain misgiving with respect to wheels subjected to the frequent and prolonged action of brakes (117) like those of tenders and tank-engines. By the rapid alternate heating and cooling, they are exposed to taking a temper which renders them liable to break, to such a point, that they may even break while at rest.

On the 18th of May 1870, an engine with four wheels coupled of 5 feet in diameter, was standing in the *Bel-Air* station (*Vincennes* line). A noise similar to the discharge of fire-arms was heard. It was the tyre of a driving wheel of *Krupp's* steel, that broke off short. The rivets holding it, the crack opened only a fraction of an inch.

This engine was provided with a very powerful brake, which the driver used in preference to counter steam (III, 203 and following). Several other breakages of tyres of *Krupp's* cast steel have taken place on the Eastern of France, and all on wheels submitted to the frequent action of brakes.

On a good number of German and Austrian railways, wrought iron is still preferred for the tyres of tender and tank-engine wheels. Others however, and among them the *Staats-Bahn* and the *Southern of Austria*, the *Würtemberg* railway, give the preference to cast steel over iron without the slightest hesitation, and put *Bessemer* steel almost on an equality with crucible steel. The Saxon railway indeed prefers the first, as less subject

to the drawbacks likely to result from the frequent and continued action of brakes (*).

315. *Examples of distances run.* — Here are several examples of the distances run by cast steel tyres from different sources of supply, on the Eastern of France, at the time of their withdrawal from work:

I. — *Engines.*

TYPE.	TYRES SUPPLIED BY.	DISTANCE RUN.	OBSERVATIONS.
		Miles.	
Engine with eight wheels coupled.............	Krupp................	77.300	Large tender.
do.............	Petin and Gaudet.......	57.857	do
do.............	do.............	54.260	do
do.............	Krupp................	53.180	do
do.............	Petin and Gaudet........	53.000	do
do.............	do.............	46.070	do
Mean.................	....	57.180	

II. — *Tenders.*

TYPE.	TYRES SUPPLIED BY.	DISTANCE RUN.	OBSERVATIONS.
		Miles.	
Ordinary tender........	Bochum (works)........	114.445	Large tender.
Idem...........	Petin and Gaudet.... ..	109.777	*Idem.*
Idem...........	*Idem*..............	106 899	*Idem.*
Idem...........	Vickers..............	98.487	*Idem.*
Idem...........	Petin and Gaudet.......	81.966	*Idem.*
Idem...........	*Idem*.............	68.746	*Idem.*
Idem...........	Bochum (works)........	63.283	Small tender.
Idem...........	Petin and Gaudet.......	53.735	*Idem.*
Idem...........	Vickers...............	52 967	*Idem.*
Idem...........	*Idem*.............	46.457	*Idem.*
Tender of machines with 8 wheels coupled.....	Krupp................	122.295	
Idem...........	Petin and Gaudet.......	111.550	
Idem...........	*Idem*............ .	82.037	
Idem...........	Krupp................	80 805	
Idem...........	*Idem*.............	80.085	
Idem...	Petin and Gaudet.......	73.514	
Idem..	*Idem*........	50.450	
Idem...........	*Idem*.............	46.097	
Idem...........	*Idem*.............	34.615	
Idem...........	*Idem*.............	31.781	
Idem...........	*Idem*.............	28.041	
Idem...	*Idem*........... ..	26.122	
Idem...........	*Idem*.............	20.237	
Idem...........	Krupp................	12.564	

(*) *Referate über die Beantwortungen*, etc.

These figures are generally low, and several even very low. Leaving the latter on one side, as arising from defective manufacture, the relative inferiority of the most of the others is explained : 1. for engines, by the solid connection of the eight wheels, the unequal wear, and the frequent putting into the lathe that it requires; 2. for tenders, by the action of brakes. Thus, the following distances effected by tyres of leading wheels of *Crampton's* engines have been recorded, also on the Eastern of France:

Naylor, Vickers (Sheffield).....................	123.550 miles.
do. do.	130.064 —
Bochum (Works).............................	117.855 —
do. do.	105.068 —

Already very fair figures, and which perhaps are even now, or will be greatly exceeded.

316. *Guaranteed distance run.* — According to the specification of the Belgian State railways, the *Seraing* works guarantee a distance run of 94.000 miles for cast steel tyres (*Bessemer*) for high speed engines and with four wheels coupled.

All put on one side before a distance run of 47.000 miles must be replaced gratuitously by the suppliers; above that mileage, they are only subjected to a penalty modified with reference to the distances run deficient. It is 2s, 5 for every 1.000 miles for diameters above 4 ft, 92, and 1 s, 12 for the less diameters. Thus for a tyre of 5 ft, 58, put on one side after a distance run of 77.500 miles, the penalty is 2s, 5 × (94 — 77,5) = 41 s, 25.

Independently of putting them on one side on account of *force majeure*, all tyres the thickness of which at the middle is not more than 1 in, 18 or the wear of which exceeds 0 in., 20, after a distance run of 15.500 miles, are considered as unserviceable.

It is clear that in principle, the guaranteed distance ought to be, every thing else equal, proportional to the diameter.

317. *Manufacture of tyres of Bessemer steel, at Seraing.* — The ingot, octogonal and slightly conical, is for a tyre of 4 ft, 92 in diameter, for example, weighing finished, 0 tn, 383, 2 ft, 00 in height, and weighs 0 tn, 44. It is heated to a white heat, hammered in the direction of its axis under the 15 ton steam hammer, and thus transformed into a disc 0 ft, 68 in thickness; this disc is punched in the centre by means of a punch pointed and conical,

under the 5 ton steam hammer, and on each of its faces, with an opening 1 ft, 0 in diameter; a result obtained by hammering alone, without any loss of material. To enlarge this hole, the disc, reheated and run on the slightly inclined horn of an anvil, is hammered under a 4 tns, 5 hammer with horizontal face. At each blow the smith turns the ring through a small angle; its inside diameter being thus carried to 2 ft, 00 at the same time that its periphery receives from the steam hammer the required conicity for about two thirds of its thickness. In the same heat, the slab is hammered flat under the 15 ton steam hammer, which reduces the thickness to 0 ft, 49, necessary limit for passing it into the circular roller, which is preceded by a new heat.

The roller has only a single groove, roughing or finishing. The upper shaft alone has its two bearings fixed. The lower shaft has only the bearing next to the gear fixed; the other is supported by the vertical piston of a hydraulic press, the travel of which does not perceptibly affect the transmission by the gearing, on account of the great length of the shafts.

The tyre thus brought into shape has only one last operation to undergo: the centering, which is done on a mandril, formed of a pyramidical block pressing segments guided by radial grooves against the inside face of the tyre.

As to the driving on (an operation preceded by another, the keying on of the axle) (318), the details into which we went on this point on (114) the subject of waggon wheels will dispense with our returning thereto. The reverse operation, taking the tyres off, is effected by heating them after having cut off the heads of the rivets, or unscrewed the bolts. Mr. *Ramsbottom* has established at the *Crewe* works a sort of large blowpipe which envelops half the periphery of the tyre in flame and by means of which it is undone in 20 minutes.

We shall not dwell on the means of fixing the tyre to the rim, nor on the attempts made to do away with the countersunk rivets, or the bolts; the latter penetrating a little way into the tyre, weaken it less than rivets, but also sometimes let it fly when it breaks. As *figs.* 2 and 3 of Pl. XXIII indicate, the engine-tyres constructed at the *Creusot* works for the *Great Eastern* are fixed by a similar process to that which Mr *Beattie* has applied to wooden waggon wheels (119).

318. *Spring wheel.* — One word only on an arrangement original, which is but on which it seems difficult to rely, in spite of the favourable opinion of several English engineers; this is the spring-wheel also called the *horse-foot* wheel of Mr. *W.-B. Adams* (Pl. LXXXVII, *fig.* 37). The rim shaped

like a donkey's back, rests by its middle on a circular blade of tempered steel bearing by its two edges on shoulders o, o' of the tyre. In this case there is no question, of course, of driving the tyre on, while hot. The parts are kept in place, on one side by the projection a of the tyre, on the other side by the rim c, c kept in by hammering over the metal of the tyre at d, that is to say, Mr. *Beattie's* process.

We may admit in principle, that a certain elasticity of the wheel, especially if near its bearing on the rail, would present some advantages; it would save both the rails and the tyres. But long and conclusive experience would most assuredly be wanted to triumph over the distrust which Mr. *B. Adams's* wheel inspires.

319. *Keying the wheels on to the axles.* — As we have seen (85), the conicit ywhich was often given, for a very short length and towards the inside, on the keying on portions of waggon-axles, has been given up, and they are generally preferred entirely cylindrical, although several specifications prescribe still the turning down the whole length to an inclination of $\frac{1}{200}$.

For engines, the keying on portions of the axle and of the nave are always turned cylindrically, and exactly to the same calibre, at least nominally. Under these conditions, all theoretically to overcome in putting the wheel in place, would only be the adhesion between the two. In fact, the workmen take care when giving a little *draw* towards the inside face of the boss, to manage also a very small excess in the diameter of the axle in order to obtain the prescribed pressure for keying on; a very considerable pressure, and which ought to amount, according to the specification of the Belgian State railways for example, to 80 tons for engine wheels.

In the high speed engine of the *Northern of France* (Pl. XXXI) the keying on part of the axle is 0 ft, 59 in diameter by in length 0 ft, 56 and consequently 1,20 square feet of surface. The keying pressure increases proportionally to the length let in of the axle, and if it has to attain 70 tons at the end of the operation, this is per unit of surface in contact: $\frac{70,00}{0,38} = 184$ tons on the square foot, or 1 tn, 28 on the square inch. This would be the measure of the adhesion proper, if it were alone in play, as would have to be admitted in the hypothesis of the mathematical equality of the diameters, excluding all compression of the axle and all tension of the boss. But if it is supposed that friction mainly has to be dealt with, friction developed by a pressure due to the axle being forced in the boss bored out a little tight; this pressure R' per unit of surface of the periphery of the key-

ing surface is evidently $R' = \frac{70,00}{f \times 1,20}$, f being the coefficient of friction. For $f = 0,25$, $R' = 250$ tons per square foot, or per square inch 1 tn, 74 ; the corresponding tension R in the diametrical planes of the nave, a cylinder the thickness of which is more than 0 ft, 29 is:

$$\frac{250 \times 0,344}{0,294} = 292 \text{ tons; or 2 tons on the square inch.}$$

But in so thick a cylinder, the distribution of the strain cannot be considered as uniform.

§ VII. — Tenders.

320. *Tank-engines.* — Engines are nearly always followed by a special vehicle, carrying their fuel and water. In Mr *Engerth's* engine, which is now almost entirely abandoned (350 and following), this adjunct was so far mixed up with the engine, as to make it an integral part thereof, and it could not be detached excepting by a long operation. We have cited also several types in which the tanks which contain the water and fuel are brought on to the engine itself. But this suppression of the tender, which has the advantage of reducing the dead-weight, is far from being always applicable. It would often lead, even while reducing the quantity of the fuel and water below what is necessary, to encumbering the engine by preventing access to the machinery and interfering with the driving. If as regards the reduction of weight, this suppression of the tender would seem especially adapted to lines with steep gradients, it raises up also from this very point of view, a well grounded objection: that is the gradual reduction of the adherent weight by the very fact of the consumption of fuel and water, so that the adhesion might fail precisely at the moment when it is most needed. This is especially the case on lines with steep gradients, the frequent slipping greatly increasing the consumption of water, and the engine is often found light when it should have its maximum weight.

The economy of a vehicle heavy by itself, is an advantage, the more considerable, the steeper the gradients, and consequently the smaller the load drawn. But this suppression is subordinate to the facility for replenishing. It is impossible then, beyond the very short journeys such as on suburban traffic, and " a fortiori," shunting engines, to lay down in principle, either the superiority or inferiority of engines without separate tender, which are called: tank-engines; it is a local question to be decided

on in each case, taking into consideration the whole of the elements; and especially the greater or less proximity of water cranes.

If, in the origin, locomotives then with very little power, had carried their supplies on them, the same principle would naturally have continued to prevail; afterwards the necessity would have been felt, beyond a certain limit, of simplifying the engine, of freeing it from those accessories possible to be brought on to a distinct vehicle; and this separation would have seemed, not without reason, to be a real progress. The tank-engine is, altogether, the exception, even on steep gradients. As to high speed engines which make long journeys without stopping, they require considerable supplies which it would be impossible to place on the engine without encumbering it unreasonably, and without often exceeding the limit of load per axle; the more so as the distribution of the weight is often modified by the very fact of the consumption (274).

However, the traction of expresses is frequently enough carried on by tank-engines, for example, on the Western of France; but the supplies of the engine not being sufficient, they have had to place, as on the *Midi* of France, the rest of the water in a tank suspended to the frame of the luggage van: a complicated and inconvenient arrangement, particularly for shunting the van by hand, which is too heavy when its tank is filled with water.

It is important that the water tanks fixed on the frame and sometimes on the fire-box itself, should be distributed in such a manner, that the consumption does not too much affect the position of the centre of gravity, and consequently the distribution of the weight suspended between the axles.

The substitution of coal for coke, by reducing the volume occupied by the combustible, has contributed not a little to multiply tank-engines. The separate tender is, on the contrary, not only indispensable, but totally insufficient for engines which burn turf not compressed. Besides the tender a special waggon is wanted, and an increase of men, in consequence of the almost continual charging of the fire then necessary.

321. *Construction of the tender*. — We can pass without hesitation rapidly over the tender, a little complicated vehicle, the types of which hardly differ, at least in Europe, and which if attached to the engine by its service, belongs in reality by its nature to carrying-stock.

It is composed of an outside frame, entirely of wrought iron, supporting a body of plate iron, ordinarily in the form of a horse shoe, containing the water, while the fuel is stored, within reach of the stoker, between the

branches, and at need, when of a light density like coke, heaped on the water tank, and kept up by stanchions on each side and behind.

On the railways in Lombardy, water tanks were employed without any middle space. The cover had a slight slant to let the coke slip forward, but this slant was insufficient as soon as the thickness of the fuel became slight. I saw on the line from *Riesa* to *Chemnitz* (Saxony) a form of body the reverse of the ordinary shape; it is bulged out towards the middle, and the coke is stored on both sides thereof. This arrangement, less simple seems to have no advantage.

The cover of the tank is provided, according to the arrangement of the arms of the water cranes, either with a single opening on the longitudinal axis, or two lateral openings; each of them receives a copper cone, pierced with holes (*c*, Pl. LXIX), and intended to retain any solid matter which might get in through the pipes.

The capacity of the tenders has naturally followed the same progression as the power of the engines, and the length of the journeys. Now-a-days tanks containing 350 cubic feet of water are frequent. The increase of capacity has been obtained, in part by increase of height; which requires evidently thicker and better strengthened plates.

For a long time, in spite of their loads being a great deal less than what they receive at present, tenders had sixwheels. This number being the less warranted as the shortness of the frame, and consequently the nearness of the wheels to each other rendered difficult to install the brakes, with which the tender is always provided. There is no hesitation now-a-days to setting up on four wheels, tenders with 250 and up to 350 cubic feet of water, and a proportional quantity of coal or coke.

In reality, the quantity of fuel at starting is not that which corresponds, as consumption, to the quantity of water, it is always more; which arises from the fact that the points of fuel supplies are more distant than water supplies. The expenditure of fuel being, in weight, at the most one seventh of that of the water, there is from the point of view of dead weight, little drawback in carrying a certain excess; it simplifies checking the fuel and facilitates the inspection. But it is important to avoid either a too considerable excess, or bad packing which would involve overloading the axles. Such is the object of the following service order (3 March 1868) of the locomotive department of the Eastern railways of France :

« The maximum load of fuel which a tender ought to contain, is limited as follows :
Large tenders with wheels of 3 ft,94, 6 tns,00.
Small tenders with wheels of 3 ft,28, 4 tns,00.

" The drivers ought so to arrange their requisitions that the quantities taken on, added to what remains in the tender, do not exceed the above weight."

" It has been found that the load often has been badly distributed on the journals of the axles; tender springs must thus be frequently adjusted like those of engines."

On some lines however, six wheels are kept to for tenders of great capacity. Such are the tenders of the eightwheeled engines of the *Midi* of France containing 10 tons of water and 3 tons of coal. The boiler contains 140 cubic feet of water. The tender of *Sigl's* eightwheeled engine has also sixwheels of 3 ft, 34 in diameter; weight empty: 12 tns, 50; water: 10 tns, 50, fuel (wood), 4 tns, 00.

The fourwheeled tender (Pl. LXXXIII, *figs.* 1 and 2), of the fourwheeled *Graffenstaden* engine weighs empty 8 tns, 00; and full 15 tns, 60; its load consisting of 5 tns, 50 of water, and 2 tns, 00 of fuel.

In North America, tenders, of large dimensions, in consequence of the distance between the water supplies, have at least six wheels and often eight; in the second case, they are like waggons, supported by two bogies, although their shorter length renders this double articulation less necessary. The Grand Trunk railway of Canada first adopted tenders with three fixed axles; according to Mr. *Watkin* manager of that line, the breakages of rails, very frequent in winter, have become a great deal fewer from the fact of the application to these vehicles of bogies similar to those of waggons.

322. *Filling the tender while running.* — It is rare that a train even at a very high speed runs more than 50 miles, without traffic considerations, or branches to serve, requiring it to stop once. In France trains run from *Paris* to *Montereau* (49 miles) to *Vernon* (50 miles), etc. But in England, the expresses go at one single stretch from *London* to *Rugby* (80 miles), from *Chester* to *Holyhead* (85 miles), etc. The Irish mail which runs this latter distance in 2 hours 5 minutes, may consume only in fine weather 280 to 300 c. feet of water; but if the wind is violent, this consumption may rise to 385 cubic feet. There are on several lines tenders containing up to 12 tons of water and 4 tons of coke; but the engineer of the *London and North Western*, Mr. *Ramsbottom*, wished neither to increase the capacity of his tenders containing 9 tons of water (a weight which he looked upon with good reason as already excessive), nor to give up long runs without stopping. He attained the object by an original and ingenious contrivance : taking up by the tender, while running, water stored in long

troughs laid down on the horizontal portions of the line. As well as the suppression of stoppages, there is this other advantage that the supplies of water being no longer localised at stations, there is a great deal more latitude for utilising the resources which are met with along the line, and that more attention can be paid in laying down the troughs to the quality of the water. Thus the engines avoid taking any in *London*, where it is of very bad quality. They start, if needs, with the tender nearly empty, and refill it while running in both ways only 9 miles from the capital. The intake tube (Pl, LXXXII, *figs*. 3, 4, 5, 7) curves upwards in the shape of a swan's neck, and finishes at the bottom by a movable appendage held up either by a counterweight, or by the working parts, and which the stoker lets down as soon as it comes over the alimentary trough. S being the vertical section of this orifice, a section the form of which is rectangular, Q the volume of water which ought to be taken up, the length l of the trough is evidently: $l = \frac{Q}{S}$. In Mr. *Ramsbottom's* tender, we have Q = 176 cubic feet, the orifice of the movable pipe is 0 ft., 410 in length, and 0 ft., 16 in width; then S = 0,0650 sq. ft., and l = 1.300 feet.

But to make this appliance work, the relative speed of the water, that is to say the speed V of the train must be at least equal to $\sqrt{2gh}$, h being the height of the top of the pipe above the trough. For h = 7 ft, 87, V = 22 feet per second, or 15 miles a hour. Experience proves that with this height and at this speed, the supply is nil. The relative speed ought in effect to surpass the theoretical value, because it is destroyed partly by the sudden deviation of the threads of liquid at their entrance into the tube, and by the friction; a column of water rests suspended during the running over the trough, in this sort of counter part of *Pitot's* tube, without rising up to the top so as to fall thence into the tender; but the increase of speed necessary is small. This speed once attained, its increase has no further perceptible influence. It is always, in effect, the same prism of water $l \times S$, which is taken up, and it is so the more rapidly, the greater the speed. Some observations made in England would seem to indicate a certain increase of effect with the speed :

At 22 miles an hour	170 c. ft.
At 24 miles —	173 »
At 38 miles —	183 »

But it is so little marked as to be simply a practical confirmation of the constancy of the effect, as soon as the speed fully attains the neces-

sary minimum. More multiplied observations would besides be required.

In England, goods trains running faster than any where else, can take advantage of this mode of filling the tender. In France it would be too near the limit, the tanks of the tenders would have to be lowered. As to fast trains, in view of which it was devised, they have a great deal of margin, and the drivers very often profit thereby to slacken speed in order to make more sure of letting down the movable mouthpiece as soon as it reaches the trough, and to let it go for the counterweight to lift it up, as soon as it approaches the end of the trough.

To reduce as much as possible the height to which the water has to be raised, and consequently the minimum velocity of translation, all the part of the tube within the body of the tender was tried to be done away with. It stopped at the floor of the tender, and was shut by a clack valve (*fig.* 6); but the primitive arrangement was returned to. The clack valve, which opposed at the same time a pretty considerable resistance to the water, shut badly, and the tender emptied.

The trough (*figs.* 3 and 8) in cast iron is 0 ft,49 in depth and 1 ft,48 broad, and is formed of lengths bolted onto the sleepers, the joints are made with india-rubber, which gives to the expansion and disturbances of the sleepers, keeping the whole thing tight. The trough is filled either by pumps or from springs. In certain cases where it is important to save the water, the inventor regulates the expenditure, by means of an ingenious apparatus applied to a reservoir in which the water from the spring accumulates. But we cannot dwell longer on the accessories of a system, the applications of which are, and will without doubt remain very restricted.

An objection which presents itself at first sight, that of the rapid freezing of such a thin sheet of water, is of little weight under the climate of Great Britain. When required, a porter breaks and takes away the ice; which is necessary, especially in the morning; but if the traffic be active, the simple passage of the pipe of the tender is sufficient in general to stop the ice from forming.

The action of the appliance could be rendered automatic and at the same time surer by a slight modification in the line. The mouth of the pipe, fixed and consequently, above the level of the rails, would plunge into the trough by the very fact of a depression of the rails of about from 0 ft, 39 to 0 ft, 46, reached by an incline and counter incline of one in 100, for the whole length of the trough.

323. *Cistern-waggons.* — Some times the necessity exists of carrying by

the trains themselves the water destined for the supply of engines. This happens when the water station only furnishes water of bad quality or when in dry weather there is not enough for the consumption of the engines. The station of *la Nouvelle* on the *Narbonne* and *Perpignan* line is in the first case; the station of *Gien*, and many others besides are in the second, during prolonged drought. They are then supplied by means of *cistern waggons;* those of the *Lyon's* line weigh, empty 5 tns, 4, and contain 4 tons of water. These two cases rarely occur. If they were more frequent, the ingenious solution invented by Mr *Ramsbottom* would naturally find an application.

324. *Tender coupling.* — Behind, that is to say on the train side, this appliance is exactly the same as that of the waggons. It includes then (*figs.* 1 and 2) a large spring R, serving for buffing and drawing, a hook C, with screw-coupling, and two buffers *t*, *t*. In front, the tender has ordinarily a spring, but it is short, serving only for drawing, and two elastic buffers a great deal less wide apart than the hind ones, in consequence of the less breadth of the engine. Nothing hinders however, the same arrangement from being applied at both ends (*figs.* 1 and 2), the two small buffers rigid in that case θ, θ, abutting against the ends of the small spring ρ. The engine has no elastic appliance when the tender has one, and *vice versâ*, so that their reactions are deadened only by a single spring. In front, the engine has only a single rigid hook and two buffers, sometimes rigid also, sometimes elastic, but at a great distance apart, because they have to correspond, in the case of traction with more than one engine, to the hind buffers of the tender of the preceding engine, and, in case of pushing the train, to those of the end luggage van.

There was long used for the coupling of the engine and the tender, a simple bar jointed on to the clip of the traction spring of the tender, having an eye to take the coupling bolt of the engine; but it was necessary then, in order to put the buffers under pressure, to have recourse to somewhat complicated arrangements. For example, the engine having its transom applied against the buffers of the tender, an excentric worked by a gearing, and pressing the spring at its middle, pushed the bar guided by a sort of hopper on the engine, until its eye corresponded to those into which the bolt had also to be put; the bolt once in place, the excentric left the spring which remained stretched. This means only gave however a uniform tension. The screw coupling with right and left hand threads (126) greatly used now-a-days, is much simpler, and allows the tension to be varied at

will, and consequently the perfect consolidation of the engine with the tender. (Pl. XXXI high speed engine of the Northern of France; T short traction spring; *t*, *t*, buffers at a distance apart of 3 ft,94 between centres).

Sometimes the spring is brought on to the engine, as in the compound engine of the *Orléans* railway (Pl. XXV and XXVI); the engine with six wheels coupled of the Western of France (Pl. XLIV and XLV); the sixwheeled engine of the *Creusot* (Pl. XLVII), T, T double springs, etc.

When the hind cross-beam is of wood, and not at all, or only slightly strengthened, the effort of traction is not ordinarily applied thereto; two strong strutting pieces riveted onto the longitudinals receive and transmit thereto this effort (engine of the Western of France, Pl. XLI, *fig.* 1, and XLII, *fig.* 1). It is however, the cross-beam itself, of wood, covered with a simple plate of iron, that fulfills this function, in the engines of the Southern of France, and the engineers do not see any drawback, even for slow speed engines which develop consequently great efforts of traction (Pl. XXIX, engines, with six wheels coupled). The coupling hook is also fixed to the cross-beam, in the engine with eight wheels coupled of the Ceinture (*Paris*) railway (Pls. LVI and LVII) but it is solidly strengthened by the struts *u*, *u*, analogous to those which receive the bolt in couplings without screws.

This engine and those of the Western of France (Pl. XLIV and XLV) of the *Creuzot*, of the *Orléans* line, with ten wheels and of the Northern of France with twelve wheels have behind large buffers at a distance apart of 5 ft,61 to 5 ft,71, whilst the others have small buffers at about 3 ft,28 apart.

This difference arises, as is at once seen from the fact, that the first are tank engines, intended to be coupled directly on to vans. They must thus have behind the same arrangements as the tender, which they are without.

325. *Coupling at two heights.* — One of the types with six wheels coupled of the *Midi* of France has been arranged by the locomotive engineer, M. *Laurent*, in such a way as to receive, when required, wheels of 4 ft,26, or wheels of 5 ft,25, which permits it to be applied to different speeds. For the same tender to be able without also changing its wheels to be coupled to the engine in the two conditions, it is provided with a double coupling o, o' (*figs.* 9 and 10); the distance o, o', is 0 ft,49, the variation of the height above the rails, of the engine. This engine *with double object* has been sometimes found fault with; the less value of adhesion corresponds in effect to the less speed, in consequence of the relative lightness of the wheels of 4 ft,26.

M. *Laurent's* idea does not seem the less susceptible of useful applications. The objection could be removed by having recourse, when required, to ballast.

326. *Coupling on lines with curves of small radius.* — We now come to one of the points of detail, on which opinions are most divided.

We have compared, higher up (188), the ordinary coupling, that is to say by a short bar jointed on to the middle of the cross-beams, to the coupling at a point more or less nearly approximating to the centre of figure. This has not, in principle, as we have seen, any advantage over the first, but the contrary, as regards the movement of vehicles through a curve. However, the obliquity of the line of traction on the axis of the line, advantageous at first, becomes excessive, above certain limits of curvature, and length of frame. It would be easy to reduce this drawback, by putting the vehicles at a greater distance apart, but care must be taken against increasing uselessly the length of the trains. It is in this respect, that it might be well to take the point of fixing not near the end of the frame, but nearer the centre of figure.

Engineers, who have believed in the utility, purely contingent, of this step from the fact that the vehicle drawn by its centre, moves on a curve, in spite of its connection with the others, nearly the same as if it were alone, have taken for the advantage, what on the contrary, is in general the drawback; for coupling by the middle of the cross-beams tends precisely to correct the effects of the freedom of the vehicles.

M. *Polonceau's*, M. *Beugniot's* and M. *Stradal's* appliances realise, indirectly, the coupling nearly at the centre of figure, or in general the equivalent of the lengthening of the coupling bar, which cannot always be effective, especially with deep fire boxes.

In the two first arrangements (Pl. LXXXVI, *fig.* 1) the coupling bar, or link of the screw coupling O A is jointed, not on to the cross-beam of the engine but on to a beam M, M′, fastened to the two longitudinals by the rods M N, M′ N′. The beam has an excess of length, which permits it to take freely with respect to the longitudinals, the positions which correspond to the sharpest curves, and the situation is the same as with a single bar of the length of O B.

With this coupling, M. *Polonceau* combined buffers, having their faces tangents to a vertical cylinder, the axis of which passed nearly through the centre of figure of the engine; a form derived from the purely gratuitous hypothesis that, in order to pass from the position in a straight line to that suitable to a curve, the relative movement of the engine with respect

to the tender, reduces itself to a rotation of the first round its axis, and in such a direction that the hind part nears the outside rail.

If this were so, the buffers would remain, in effect, in contact by their maximum lengths on the side of the outer rail, and by their minimum lengths on the side of the inside rail. But each of the vehicles tends, on its own account, to grind the outside rail with the flange of its front wheel (178, 188) and it obeys this individual tendency the more, the less the mode of coupling affects its freedom; the end of the engine goes oblique in that case towards the inside, the front of the tender towards the outside of the curve, and it may happen that the sum of the corresponding lengths of the buffers is greater on the side of the less interval, and *vice versâ*, so that the form indicated works in a contrary way.

The more simple expedient of M. *Stradat*, is not a geometrical solution but an approximation, quite sufficient at the same time. (Pl. LXXIII, *figs.* 11 and 12).

The coupling bar is terminated on the engine side by a double cross piece amb connected by the vertical pins, a, b to rods of equal length l, l' jointed on the axes K, K′.

The effect of traction, resulting from the reactions of the rods l, l' on the cross piece ab, is only directed along the bar MA, when this bar coincides with the axes of the engine and of the tender, that is to say in a straight line. As soon the line of these axes is broken (*fig.* 12) the reactions of the rods on the cross piece are no longer symmetrical relatively to the bar, and the effort which the latter transmits is no longer directed along its axis A′M′, but along the straight line A′s, s being the meeting point of the two rods Ka', Kb'. The right line A′s meeting the axis of the engine at T, the position is the same as if the coupling were done by a simple bar A′T, jointed at T, as it is at A′. The position of the point T, varying little within the limits of the angular variations of the two vehicles, the length of the fictive bar is sensibly constant.

Without condemning these contrivances in an absolute manner, it is certain that their utility is only felt in the case of very long vehicles and very sharp curves, and in the most of the cases where they were applied, they could perfectly well have been dispensed with.

Several engines of the *Orleans* system had *Polonceau's* coupling put on. Lengthened experience on several lines, among others on the very tortuous line from *Moulins* to *Montluçon*, has brought out neither perceptible diminution of the wear of the tyres nor improvement in the steadiness of the running of the engines. A sterile complication has consequently

been given up; sterile at least under the conditions in which it was applied; the limit of radius 984 feet, was not low enough to render an increase in the length of the traction-bar of use, especially in such a proportion.

This coupling was introduced onto the eight wheels coupled engine of the *Orleans* system (Pl. XLVIII) The points *o*, *o*, at which the draw rods *t*, *t*, are attached, are in the middle of the space between the axles, that is to say, considerably in front of the centre of figure.

If the utility of this apparatus had been fully established for engines with eight wheels, it is evident that there would have been no hesitation in applying it, *a fortiori*, to the tenwheeled engine, considerably longer, of the same system (Pls. LVIII and LIX). Now the latter has only simply the ordinary coupling fixed on to the cross-beam.

Stradal's apparatus, is the one which has received by far the most numerous applications, which it owes rather to the incontestable advantage of its simplicity, than to any profound conviction of its utility. It has been applied, among others, to the eightwheeled engines of the *Semring*, to those of the Northern of Spain (Pl. LI), and we may admit, although without sufficient proofs, that it is warranted, at least in the first case, on account of the sharp curves (623 feet).

Similar in principle, to M. *Polonceau's*, the mode adopted by M. *Beugniot* for the connection of the engine and tender, is combined with a peculiar arrangement. The front of the tender forms a sort of bench, which is placed under the frame of the engine, the fire-box of which overhangs, and this frame rests on the tender exactly above its first axle but by the intermedium of very flexible springs, so that the load thus brought onto the tender at the expense of the adherent weight is always very slight. The double aim which the inventor had in view was to improve, at the same time the distribution of the weight (a result which would be equally obtained by a convenient arrangement of weight towards the front) and the steadiness of the engine, the vertical and horizontal reactions of the tender opposing, the ones the tendency to gallop, the others the tendency to swinging. The engines of MM. *Behne* and *Kool* (Pl. LXXXVI, *figs.* 2 and 3), which ran on the *Hanover* and *Brunswick* railways, presented an analogous arrangement. The tender carried, moreover, two buffers with cross springs T, T, which acted, as the friction of the longitudinal ordinary buffers, to hinder the relative oscillation of the two vehicles without rendering however the system too rigid.

327. *The coupling of the high speed engines of the Austrian railways.* —

On lines with great radii of curvature, the engines have a long wheel base, and when required, their steadiness at high speeds may be improved by tightening up the tender buffers on the hind transom.

But on lines with sharp curves the length of the wheel base is limited, and the overhanging of the engine more considerable. Coupling the buffers with pressure would then be as necessary for regularity of running on a straight line, but it is precisely then it is impossible; much tightening would interfere, too much, with the flexibility of the system. The tender can only in that case very slightly restrain the transverse oscillations of the engine, less steady by itself; and at the same time, the interposition of the spring, although stiff, hinders the tender from following exactly, in diminishing them, the recoil movements of the engine.

It seems then perfectly logical under these conditions of line to renounce the two points which characterise the ordinary coupling, that is to say elasticity, and the double articulation of the connecting rod, a simple bar or screw coupling.

Such is the course they have adopted since 1869, on the Austrian *Staatsbahn*.

The tender carries in front (Pl. LXXXVI, *fig.* 4), a sort of short perch solidly connected with its frame, and which passes under the platform of the engine and takes a simple bolt.

Experience seems to have completely sanctioned this modification. The engine being no longer able to oscillate, neither lengthways nor crossways, without drawing the tender into its movements, these oscillations have almost entirely disappeared.

328. The connection of the engine and the tender is always completed either by two guard chains, or by two long links fixed to the engine, and in which play two pins fixed to the tender. In consequence of the slight travel of the spring, these chains or links have only a slight excess of length, so that if the coupling proper fails, the engine acts on them only with a slight momentum. In this respect, these appliances are under more favourable conditions than the guard chains of carrying stock (131).

As to the connections between the water tank and the boiler, although the flexible tubes (τ, τ, *figs.* 9 and 10) greatly used now-a-days, costs a great deal less than pipes entirely metal, with socket joints, it is not proved that they are, in reality, more economical

CHAPTER VII

LOCOMOTIVES, FROM THE POINT OF VIEW OF CURVES. — MODIFICATIONS WHICH DO NOT AFFECT THE PARALLELISM OF THE AXLES.

329. We have already remarked (174) that locomotives are, as regards running through curves, placed under much more difficult conditions than carrying-stock. They have only the advantage, and but in certain cases, from a single point of view (and that is a secondary one), that of the suppression or diminution of the sliding at the tyre; when an engine is intended specially for a line with a great many curves of small radius, it is natural to force in consequence the inclination of its tyres. It is thus that the commission appointed by the Austrian Government for the competition of the *Semring* proposed at the end of a prolonged examination of the four competing engines, to carry the conicity of the tyres to $\frac{1}{7}$ while the inclination of the rails is $\frac{1}{16}$ only. On the *Steïerdorf* line the conicity is for engines, as well as for waggons $\frac{1}{10}$, that is to say, equal to the inclination of the rail. The elements of this small line are thus in accordance with each other. But its waggons with their conicity of $\frac{1}{10}$ run on great lines, where the rails are inclined $\frac{1}{16}$. A conicity of $\frac{1}{7}$ would have been necessary to get completely rid of the sliding at the tyres, on curves of 374 feet.

In France there is only one example of this discordance, quite local besides, between the conicity of the tyres and the inclination of the rail. M. *Forquenot* chief locomotive and rolling-stock engineer of the "*Orleans*" system, has carried to $\frac{1}{12}$, the conicity of the wheels of the engines, which run on parts of the system where the radius is as low as 1000 feet. It might be feared that this excess of the conicity over the inclination of the rail ($\frac{1}{20}$) would have the effect, not of turning the rail over, but to hasten its destruction because of the line of bearing being carried over to the inside edge. It is not so; the permanent way department has made no objection against a discrepancy, which, within the limits in question, has no drawback. The rail profits, moreover, as well as the tyres, by the diminution of the sliding at the tyres; perhaps even a certain excess of the conicity, over the inclination of the rail is advantageous to it, as we have already said in treating of permanent way (I, 50).

But it is with respect to the conditions of flexibility that the engine is little amenable. The leading axle, unless guided by a particular arrangement, and the driving axle, whatever may be its position, do not yield to the convergent play which the axles of carriages and waggons admit of; it would be however more necessary in engines, especially in those of great power, and consequently with a greater length of base. On the other hand if the low speed with which the engine has to do its work, requires all its weight to be adherent, the coupling rods extend the condition of parallelism to that axle or to those of the axles which without that would escape this necessity. Now, very sharp curves, and very stiff gradients very often are found on the same line, although combined together as little as possible. It is only by twisting the line about and breaking up the gradients that we succeed, not without great cost and heavy working expenses, in overcoming the obstacles which obstruct railways in mountainous countries; so that locomotives must combine these three features: 1. great power and consequently a long boiler, and a great distance between the end axles: 2. total adherence, and consequently coupling together of all the axles; 3. flexibility, or more generally the faculty of modifying the base of support in accordance with the curves, so as to insure freedom in running through them.

We shall first examine the different means of realising more or less this flexibility, by sacrificing, if needs must, a part of the adhesion, and we shall see, by examples, within what limits of radius of curve, and of the distance between the axles, each expedient attains its aim. Farther on we shall see at what cost, that is to say, what is, for waggons and engines, the increase of resistance caused by curves. But the estimate of the resistance on a straight line, ought evidently to precede that investigation.

It is clear that a notable reduction in the gauge of the line allows the radius of the curves to be lessened. The difference between the distances run by the two conjugate wheels diminishes in the same ratio as the gauge; and, on the other hand, the length of the vehicles and consequently the space between the axles diminishing naturally in consequence of the relation of the divers dimensions to each other, the conditions of the inscription of the flanges, and of convergence, or at least of the versed sine to allow for, are the easier to fulfil, with an equal radius, the narrower the gauge is.

The reader is aware that it does not enter into the plan of this work to study the stock of narrow gauge lines. We make no exception but for those on which the reduction of the gauge is accompanied either by the adoption of a special mode of traction, as on *Fell's* railway, or by some peculiarities of construction. Let us mention, in this category, the small

engines constructed by Mr *Ramsbottom* at the *London and North Western* shops, at *Crewe*, for the use of the works. The line is on a gauge of only 1 ft, 48. The engines have inside cylinders, with wheels 1 ft, 31 in diameter and are suspended on simple springs of india-rubber; they carry their water, and weigh loaded 2 tns, 5. They are 7 ft, 5 in length between the buffers, 2 ft, 5 in width, with 3 feet base, and run easily, without requiring any special arrangement, through curves and counter-curves of 14 ft, 75 radius.

330. For the ordinary width 4 ft, 92 from axis to axis of rails, the Union of German railways admits the following relation between the radii of curves, on a main line, and the length or maximum wheel base of engines with parallel axles (*):

Radius :	Wheelbase :
Above 1.968 feet	19,68 feet.
— 1.968 —	19,03 —
— 1.804 —	17,71 —
— 1.640 —	16,40 —
— 1.476 —	15,09 —
— 1.312 —	13,78 —
— 1.148 —	12,47 —
— 984 —	11,15 —
— 820 —	9,84 —

under 984 feet, they recommend recourse to be had to articulated trucks, or analogous arrangements.

331. *Necessity of longitudinal play of the axles. — Disadvantage of doing away with the flanges.* — To pass from the position which is suitable for a straight line, to that which suits, theoretically, on a curve, each axle, except the middle one, ought, as has been indicated (183) to take relatively to the frame of the vehicle, a double movement: 1. a translation along its axis; 2. a rotation round its centre. But these two movements are fortunately far from being necessary in the same degree; the first, which allows the parallelism to remain, suffices in most cases; let us first occupy ourselves therewith.

(*) *Vereinbarungen*, etc., of 1871. — Locomotives, art. 104.
The conventions decided on by the technical commission of the Union of German railways, after the *Dresden* meeting in 1865, have been revised and a little modified in consequence of the discussions which took place at the meeting held at *Hamburg* in 1871.

When the play of the line (I, 199) becomes insufficient, a vehicle carried by more than two axles requires on a curve, as first condition, a *relative* displacement of the axles in the direction of their length. The versed sine can, rigorously speaking, be partly compensated for by the suppression of the flanges of the middle wheels (313). But the conicity of their tyres might then also be dispensed with, which, without that, would act in a contrary way, throughout the whole length of the curve, as takes place, but only or principally on entering the curve, with the hind axle (178). We should always look twice, before sacrificing such appliances of safety as flanges. *Robert Stephenson* who during a certain time, suppressed without scruple those of the middle wheels, soon returned to them.

If the middle wheels are without flanges, and the leading axle quits the rails, the running completely off of the engine, and all the consequences thereof is inevitable. If the middle wheels have their flanges on, they can temporarily make up for the front axle being off the rails, guide the engine and keep it on the line, until the driver stops, or until the front wheels have themselves got onto the rails again.

Examples. These facts are not as rare as one might imagine. Here are two recent examples. 1st On the 17th February 1872, the engine of the Indian mail ran off by the leading pair of wheels near *Pont-de-Veyle* (line from *Mâcon* to *Bourg*). The train was stopped in 560 yards. The effects were confined to the breakage of two rails, 174 chairs and 50 fish plate bolts. Without flanges on the middle wheels, it would not likely have come off so cheaply. The speed was scarcely more than 33 miles an hour, which was certainly not excessive. The engine, No 382, was with front wheels coupled 5 ft, 28 in diameter. They were on a curve of a mile and a half radius, which is practically a straight line.

2nd On May 7th 1872, engine No 632, with hind-wheels coupled, ran off the line by its front wheels, near *Cannes*, and like the preceding one, without apparent cause. But after running 250 yards the wheel which was off on the inside, struck against a guard-rail on the same side of a level crossing, and the two wheels got onto the line again themselves. It is easy to see, in the state of things indicated, either that the inside wheel must have mounted over the guard-rail, which would have made matters worse; or that the other must have got onto its rail, which put an end to the accident. These two effects are nearly equally possible, if the guard rails are on the level of the main rails. There are more chances of the second, which occurred in the case in question, if the guard rails are on a higher level than the rails.

Care must then be taken not to give up the flanges; all that can be done

is to thin them. The conicity ought besides to be also kept, the relative displacement of the axles putting it within normal conditions.

We have already pointed out (176) the all special importance of longitudinal play in the leading axle, for passing easily, without shocks, from straight lines onto curves, and *vice versâ*. This condition is more essential still for the engines, heavier, often longer, which guide the whole train, and the running of which off the line may have much more serious consequences, than in the case of a simple vehicle. This play avoids the too sudden lateral deviation of the whole mass of the engine; if the axle is fixed invariably to the frame, the whole mass must suddenly change its direction, the impact of the rail against the flange must then become very intense. If on the contrary the guiding axle can effect its movement of translation without drawing with it instantaneously the whole mass, the deviation of the latter is gradually effected without shock. The play compensates besides, for the versed sine of the arc of the base, either by itself, or with the help of the longitudinal displacement of one, or of several other axles. It greatly retards the wearing of the leading flanges, which when there is no play, constantly grind the edge of the outside rail and wear thin much more rapidly than those of the trailing wheels. At the beginning of a curve, the reaction of this rail drives the pair of wheels towards the inside; this relative displacement diminishes afterwards on account of the gradual change of direction of the frame itself, and it acquires a value, which it keeps as long as the engine is running through the curve, supposed of constant radius.

This displacement is besides a function of the radius, and of the distance apart of the axles. If in a sixwheeled engine the hind-axle has play, as well as the front one, their two individual displacements combine to compensate for the versed sine of the arc, the chord of which is the distance between the axis.

It has been sometimes made out that, in a vehicle with six wheels, it is indifferent to which the play should be given, to the leading axle, or to one of the two others. That would be correct if it were only a question of compensating for the versed sine. But with regard to the ease of entering and leaving a curve of small radius, the moveability of the leading axle has incontestable advantages; it may be useful to extend this moveability to others; but for that one, it is altogether essential.

In the engines with twelve wheels of the Northern of France (262), the two end axles, 19 ft, 68 apart, had at first, a total play of 2 ins, 35, corresponding to the versed sine of a curve of 160 yards radius. At a very low speed, so considerable a play is admissible; but even with the speed of goods-trains,

it ought to be controlled, without which the axle, free to "float" under the engine, would seriously affect its steadiness. The axle must not be permitted to displace itself relatively to the frame without overcoming a force of, as much as possible, an intensity increasing with the amplitude of this displacement, and of which the initial value is sufficient to prevent the axle from displacing itself under the influence of the simple accidental causes which affect it on straight lines.

332. *Means of regulating the use of the play.* — There are different means of restraining the freedom of the axles, to prevent their taking the longitudinal play, excepting when, and within what limits it is necessary.

1. *M. Caillet's apparatus.* The axle can only displace itself relatively to the frame, by compressing an elastic system placed directly above it.

The apparatus arranged for engines with inside frames is composed (Pl. XVIII, *figs.* 10 to 12) of two springs r, r', fixed onto the cross-beam E, the prolongations of which enter freely into the holes of the pressure rods t, t' of the bearing springs S, S. On these prolongations are fitted sockets with a fork C, C′, abutting on one side against the pressure rod and on the other against the extremities of the spring r. A nut e (*fig.* 12) serves to give the latter the suitable initial set, and, at rest, the claws of the sockets C, C′, are applied without pressure on to the rods t, t'. These rest on the axle boxes by the intermedium of plates (*fig.* 10) the bearings of which are well fitted and oiled. The play of the axle results from the excess of the distance between the lateral flanges of the axle-box over the breath of its guides g, g (*figs.* 11 and 12). As soon as the axle, driven by the pressure of the outside rail on the flange, slides under the plates of the pressure rods, the axle box on the same side takes the socket C with it by its shoulder M (*fig.* 10), and compresses the two springs r, r'. This pressure is counteracted by the reaction of the spindle t' against the slot of the socket C′.

As long as the pressure of the axle box on the shoulder M, does not surpass that which the nut e exerted on the socket, no displacement is produced, the pressure at M, simply being substituted for that of the nut. It is only under a greater pressurethat the socket moves, separating itself from the nut e, and that the springs r, r' are compressed.

It is clear that in this movement the inside axle-box leaves the shoulder of its socket, by a distance equal to the displacement of the axle, with which it is solidly united.

In leaving the curve, the additional tension of the springs r, r', brings the axle back to its normal position.

The effort to be applied to the flanges increases with the amplitude of the displacement, and for the same amplitude, it is so much the greater, and the flanges wear so much more, the stiffer the springs are; it is desirable then to reduce it as much as possible, stopping at the point, where the excess of freedom of the axle would engender, at a high speed, the swinging movement on a straight line.

Play is generally given to the axle-boxes in their guides to the extent of 0 in, 39 on both sides of the mean position, and to the springs a flexibility of 0 in, 39 per ton and an initial strain from 1 ton to 1 tn, 2; each spring bending thus, at the maximum, 0 in, 20, which corresponds to a strain of 0 tn, 5; the greatest pressure varies according to the initial stiffness from 1 tn, 5 to 1 tn, 70; this is then, also, the reaction of the outside rail on the flange, to which figure has to be added the friction of the axle-boxes on the spindle bearings or at most $\frac{1}{30}$ of the load on the axle.

This appliance is not much used in France, where they generally prefer inclined planes (4); it is more so in England, where it is known under the name of "*Slaughter's* translation apparatus", it has been applied, for example to eightwheeled coupled tank engines, constructed by the *Avonside* company for the *Vale of Neath* railway. The four axles are provided with these apparatuses; experience has led to the regulation of the initial stiffness of the springs to $\frac{1}{7}$ of the load on the axle. The tyres, in cast steel it is true, wear very slowly; the curves are in general moderately sharp, except those in the neighbourhood of *Swansea*, the radius of which is as low as 166 yards, and which the engines in question, with a wheel base of 15 ft, 28 run over very easily. The first and the second pair of wheels, as well as the third and the fourth are connected by compensating beams (292).

2. *Movement of the bearing springs by the axle.* — The regulating function can be fulfilled, by the suspension itself, as is seen for example, in the *Vienna Raab* engine, already cited (258). The longitudinal displacement of the hind axle (the only one which has any play), taking along with it the springs, causes the rods, at first vertical, which suspend the longitudinals to the springs, to take dissymmetrical inclinations, whence results the tendency of the axle to return its mean position. In this case the same contrivance as to the transversal play or convergence in waggons is applied to the longitudinal play (70, 176, 183); but it is combined with the use of *Baillie's* spring, brought in under a form which has the inconvenience of reducing the width of the elastic base.

3. *Osselets.* M. *Polonceau* frequently employed (and it still is employed), a piece of steel in shape of an isosceles triangle with rounded angles, placed

between the widened base of the bearing rod of the spring and the top of the axle-box. When the axle is driven in one direction or the other, by the pressure of the outside rail on the flange, the triangular piece of which the lower end is drawn along in the movement of the axle-box, inclines to the vertical, so that the rod only rests on it by the edge a of its foot (Pl. LXXVIII, *fig.* 39). It is easy to determine the effort $2x$, necessary to deviate the axle by a given quantity δ, or the equal effort which tends to bring it back to the mean position. P being the load on each box, c the length ao, $2d$ the length ab (ordinarily, $2d=c$), the triangular piece abo (*fig.* 40) is, on both sides of the engine, in equilibrium under the action of the couples, P, — P; x, — x; whence:

$$x\sqrt{c^2-(d-\delta)^2}=\mathrm{P}(d-\delta), \quad x=\mathrm{P}\frac{d-\delta}{\sqrt{c^2-(d-\delta)^2}};$$

the effort applied by the rail on the flange, at the instant when the displacement is δ, is then:

$$2\mathrm{P}\frac{d-\delta}{\sqrt{c^2-(d-\delta)^2}}.$$

Its initial value, corresponding to $\delta=0$, is: $2\mathrm{P}\dfrac{d}{\sqrt{c^2-d^2}}$; it diminishes when the amplitude δ increases and would be nothing for $\delta=d$, which is evident, the right line ac being then vertical. If δ were $>d$, a would be negative; the action of the load P, instead of tending then to bring back the triangular piece and the axle to their mean position, would tend on the contrary to move them from it; the triangular piece would act in the contrary way. Its breadth and that of the foot of the rod must then be great enough to prevent this circumstance ever occurring.

The diminution of the returning force, when the amplitude of the displacement increases, is a drawback. It is, by the way, less marked than it seems at first to be, P increasing when δ diminishes; but this effect is open to criticism in another respect: as the line ao approaches the vertical, which it ought never to reach, the rod rises, and consequently the load on its spring increases, the more, the stiffer it is. The distribution of the load between the axles is then modified by the play of the regulating apparatus.

This imperfection is, moreover, nothing serious. The principal drawback of the *osselet* is not in that respect, but in the concentration of the load on surfaces far too small. The *osselet* wears, or gets out of shape; or indeed if it is so hard as to resist, it works itself into the top of the axle box, which it tends to drive in.

Instead of being free, the *osselet* is sometimes attached to the axle box

by a pin g, forming a spindle which supports the load, and transmits it to two projecting lugs on the axle box (*fig.* 41); this arrangement may be preferable to the preceding one, the pin on which the wear is concentrated being easy to replace. It has been applied to engines with six coupled wheels for mines constructed by *Black, Hawthorn and Co.* The hind axle only is provided with *osselets*, which is a mistake (330).

4. *Inclined planes.* — The two drawbacks, that is to say the excessive concentration of the pressures, and the diminution of the force when the displacement increases, are avoided by an arrangement generally preferred now-a-days : inclined planes. The foot of the spring rod is formed underneath of two inclined planes in contrary directions. The bearing surface of the axle box is similarly shaped; when the axle is in its mean position, the load is divided equally on the two symmetrical inclined planes. As soon as the axle is driven over, the load is then only carried by the planes of one side, and on a portion of their surface of more or less extent, and the box tends to slide on this surface in order to regain its mean position.

P being the load on axle box, α the inclination of the planes, δ the displacement of the axle, $2x$ the horizontal force necessary to produce it, the motorg power $2\delta x$ is equal to the sum, on both sides of engine, of the resisting actions of gravity and of the friction on the planes; we have then:

$$2\delta x = 2\left(\mathrm{P}\delta \tang \alpha + f\mathrm{P} \cos\alpha \times \frac{\delta}{\cos\alpha}\right), \quad \text{whence} \quad 2x = 2\mathrm{P}(\tang \alpha + f),$$

δ has disappeared because P is supposed to be constant; but in reality, P is a function of δ, and increases with this length on the same grounds as in the preceding case. The force $2x$ applied by the rail to the external flange varies then, according to the conditions of flexibility of the springs. The stiffer they are, the more the same elevation of the spring rod corresponds to a notable overload, and the more the distribution of the weight is in that case affected by the play of the inclined planes.

If the inclination is $\frac{1}{10}$, a displacement of 0 in,39 corresponds to an elevation of the middle of the spring to 0 in,04; the flexibility of locomotive springs being from 0 in,24 to 0 in,31 per ton, that gives an overload of 1 ton $\times \frac{1}{7}$ or about 308 lbs, or 616 lbs for the pair of wheels; a very small figure, relatively to the other disturbances of the distribution of the load.

As soon as the displacement commences, the bearing surface is immediately reduced to one half; then it diminishes more and more as the axle leaves its mean position; moreover the foot of the spring rod overhanging

on one side of its axis tends to turn over. This last drawback can be lessened by fixing together the two contrary planes laterally instead of base to base. There are then in reality, so as to completely avoid overhanging, three planes; that of the middle inclined in one direction being comprised between two planes of half the breadth, and both inclined in the other direction (Pl. LXXXVI, *fig.* 5). The bearing then takes place according to the direction of the curve, either on the middle plane, or on the two end planes.

Instead of being applied to the foot of the spring rod, and to a dish brought on to the top of the axle box, the inclined planes may be brought underneath the box, and on to the bearing. It is, then, the latter only that the axle takes along with it in its movement, and the axle-box is let into the guard plates without play; this arrangement (Pl. LXXXV, *fig.* 6), applied for the first time by M. *Forquenot* to « *le Cantal* » engine (261), allows the bearing-surface to be considerably increased; the oiling is easier and better over the bearing, than over the axle-box. The play, on each side, adjusted for running through curves of 656 feet radius is :

For the middle axle (driving)...........................	0 in,00
For the second and the fourth..........................	0 » ,27
For the first and the fifth............................	0 » ,67

As has been pointed out (95) the inclination has been brought lower down still in England in carrying-stock, that is to say on the lower face of the bearing and on the journal, but with quite another object; it was not intended thereby to control the displacement of the axle, but to completely suppress it, at the same time doing away with the neck of the journal, which was looked on as a cause of fracture, by reason of the shocks which it receives from the bearing. Such is also, in engines, the object of journals (Pl. XXIII, *figs.* 2 and F, *f*, Pl. XXII, *fig.* 3), with curved or biconical sections. It is clear that the bearing, having the same shape, fits on to the two conical portions of the journal, and all relative movement between it and the axle is impossible.

Inclined planes are now-a-days the most common expedient for facilitating the passage of engines through curves, by means of the simple longitudinal displacement of the axles. All the engines of the *Orleans* system have them in front, without even excepting high speed engines; these require them more than the others; but it might be feared that the freedom, even controlled, of the leading axle, might affect the steadiness on a straight line. It is not so. The trial, on the *Paris* and *Méditerranée* line, of inclined planes, to the leading wheels of a *Crampton's* engine has, in the same way,

fully confirmed the advantages, without restriction, of this appliance for high speed engines, and especially with a long wheel-base; the application would have been made general on that system of lines, if the type itself had not been abandoned.

For engines with more than four wheels coupled, the application of an amount of play large enough to warrant the use of inclined planes, only requires spherical bearings on the coupling rods and on the crank pins, and a vertical articulation, if these rods are placed in the same line, which is nearly always the case (V, V, Pl. LXII, *fig.* 1; H,H, Pl. LXV and LXVII).

The six wheels coupled engines of the *Midi* system of lines, have inclined planes only on one single axle; this is, very properly, the leading one (Pl. XL, *fig.* 4); as the figure shows, they are put side by side; the total amount of play is 0in,63; it is sufficient to insure these engines running easily through curves of 984 feet radius, and even below that.

The tank-engines with six wheels coupled of the *St. John's Wood* line, which branches off at the *Baker-street* station of the Metropolitan Railway (*London*), have inclined planes to the two end axles, carrying the load by an outside frame; the driving axle, cranked, has inside and outside journals.

The engines with eight wheels coupled of the line from *Alais* to *Brioude* (*Méditerranée system*) are similarly provided with inclined planes on the two end axles. With a total play of 2 ins,00 the engines, with a distance between the axles of 13 ft, 14 and 32 ft, 28 total length, run through curves of 656 feet, easier than engines with three fixed axles, and with a wheel base of 10 ft, 7 and total length of 27 ft, 13.

It seems that low speed engines can take the play, without any arrangement being required for controlling it. It was thought necessary, however, on the *Paris*-Ceinture line, to suppress by means of liners, the play given by M. *Beugniot* to his eight wheels coupled engines (Pl. LV to LVII). It cannot be denied that a certain amount of play is useful for engines which frequently shunt, and consequently, are constantly running through siding curves; and if freedom seemed to present some drawbacks, it would have been better, without doubt, controlled than suppressed.

5. *Axles forming an articulated parallelogram.* — The principle of the longitudinal displacement of axles, always parallel, had been already applied in the United States, by *Baldwin*, but in a much less simple manner. It was required, in an engine with eight wheels coupled and inclined outside cylinders driving the third axle, to give this faculty of displacement to

two contiguous axles, the two leading ones (*). The principal frame inside, did not bring the load directly on them, but by the intermedium of a small special frame; each of its longitudinals took hold by cylindrical slides, of boxes also cylindrical, and receiving at its middle the load of the general frame by means of a rocking support; the rectangle formed in a straight line by the two partial longitudinals and the two axles, formed thus an articulated system, which could give way on curves under the action of the rails on the flanges. On a straight line, each of the axles was kept in place by its connection with the other, the one being unable to take a certain longitudinal displacement without the joint axle taking an equal and contrary one. Now, on a straight line, the accidental causes which induce the displacement of each axle can only be concordant by simple fortuitous coincidences. On a curve, the contrary displacements of the two axles combine to make up for the versed sine, and to facilitate the yielding of the engine to the curve. The two front coupling rods have spherical bearings, the hind one does not want them.

6. *Axles coupled by an oscillating lever.* — But the same result can be more simply obtained by M. *Beugniot's* method. This able engine builder at first applied the principle of *Baldwin's* arrangement to la *Rampe* engine (Pl. LXXX, *figs.* 4 to 6), a heavy, complicated machine but at the same time a real and interesting study, in which several novelties were submitted to experiment; it merits in this respect some little notice:

Heating surface : 1.862 sq. ft. (tubes 15 ft,75 long) limit of pressure : 7 atmospheres; pistons : 1 ft,77 × 1 ft,84.

(These unfavourable proportions were the consequence of the small diameter of the wheels; with a longer stroke, the big end would have gone down too low.)

8 wheels coupled... Diam. 3 ft,94. Wheel base... 12 ft,80.

The considerable weight arising from the great heating surface, and also from the arrangements adopted, did not permit the engine to carry its own fuel and water.

		Tons.		
Engine (filled)	1st axle	11,80	47,30 Adherent weight.	70 tns,82. Total weight.
	2nd and 3rd axle	23,60		
	4th axle	11,90		
Tender will 7 tns,50 water and 2,00 of coals.	1st axle	5,20	23,52	
	2nd axle	9,16		
	3rd axle	9,16		

(*) The inclination of the cylinders allowed the connecting rod to be applied directly to the wheel, carrying the coupling appliance to the outside.

The cylinders in this engine, are neither inside nor outside properly speaking, but are both at once, the pistons having their axis in the mean plane of the wheels, and each of them driving the front axle, by an inside crank as well as an outside crank arm.

« This arrangement » says M. *Beugniot* (*) « joined to the counterbalance weights distributed over the eight wheels (and which only give vertical equilibrium), very greatly reduces the actions due to the parts in motion. »

A statement which is without foundation as regards the forces of recoil (280) because the masses of the interior machinery act in this case in the same direction as those of the coupling, without taking into account the additional masses, such as the cross head T (*figs.* 4 and 6) of the piston.

The outside frame carrying the cylinders and taking the coupling, only supports one quarter of the suspended weight, and brings the load by outside journals on to the four axles, which have a play of 0 in, 79 in the guard plates, on both sides of their mean position. The other three quarters of the suspended weight are carried on four inside longitudinal beams *l*, *l*, taking on the journals by supports with pivots, and each receiving its load from a spherical cap S in the springs *s*, *s* of the fire-box (*fig.* 5).

Each axle has thus four journals, two outside and two inside, and the suspended weight is borne by sixteen springs, and indeed by eighteen; for the hind end of the engine rests on the tender, the front axle of which has also outside and inside journals; the first carrying a slight part (from 3 tns, 5 to 3 tns, 8 at most) of the weight of the tender. The second journals are loaded by very flexible special springs (0 in, 79 per ton) the statical tension of which is regulated by means of pressure screws, on which the crossbeam of the engine rests.

This arrangement, which has nothing in common with *Engerth's* engines, leaves the independence of the en ine and the tender intact as in ordinary locomotives. It only reduces very slightly the adherent weight. Its sole aim is to give to the engine more stability, particularly when, on a straight line, or down an incline, it has to increase its speed somewhat.

Compared to *Baldwin's* engine, this one presents two important improvements: 1. the longitudinal displacement applied in the one, only to two axles, is extended, in the second, to all four axles; 2. the two spherical supports bringing, in the first, the load on the two movable axles, have to transmit the half of the efforts of the engine, drawing or shunting. In the

(*) *Mémoire sur une locomotive de montagne,* etc., page 27.

second one, the four spherical supports S are completely withdrawn from these efforts, brought on to the guard plates of the general outside frame; this is indeed the main function of this frame.

But M. *Beugniot* soon recognised that the special frames are in no way necessary, and that it is sufficient, by giving the two axles proper play in their guard plates or in their bearings, to establish the connection between them by a simple beam, oscillating round an axis fixed to the general frame, and jointed at each end on to a ring, taking of the axle between two collars.

M. *Beugniot* has constructed, several engines with eight wheels coupled for the Central Italian railways; in which the first and the second axle, and the third and fourth are respectively connected together by a beam.

These are the principal elements of the l'*Appenin* engine :

Heating surface....	fire-box	113	2.053 sq. ft.
	tubes..........	1.940	
Boiler.............	water	141	c. ft.
	steam.........	884	—

Effective pressure : 8 atmospheres.
Pistons : 1 ft,97 × 2 ft,00.
8 wheels of 3 ft,94.

The same apparatus has been applied as a trial, to one of the twelve-wheeled engines of the Northern of France (262), by carrying the total primitive play from 2 ins, 36 to 3 ins, 58 and joining together, which is the necessary consequence of the mode of connection, the first and the third axle on the one part, and on the other the fourth and sixth.

The position of a water tank under the boiler, that of the wheels under the fire-box, and the passage of the steam and water pipes between the grate, and the axles, placed this application under very difficult conditions. On this account particularly it is interesting to dwell on it (Pl. LXII, *figs.* 2, 3, 4 and 5). The plate iron beams *b*, *b*, are placed under the axles; each of them rests by its bearing on a spherical pivot P, fastened to a cross beam *t* rivetted onto the longitudinals. At each extremity the beam carries a fork which catches into recesses in the double socket *m*, *m*, brought onto the axle. The beam of the front group is placed along the axis; that of the hind group is by reason of the parts to clear, put over on the right, which is however quite a matter of indifference.

The intermediate axle of each group drives, and is the only one without play; which reduces the fixed distance between the centres, to 12 ft, 20 instead of 19 ft, 68. This is still a good deal for very sharp curves. But the flanges

of these two pairs have been thinned, which increases as regards them, the play of the road, and facilitates the freedom within the rails, of these two pairs of fixed wheels. The cylindrical crank pins of the four end axles have been replaced by spherical pins, so as to put less strain to the coupling rods and so on. Of course the bearings of the bars had to be modified, in consequence; a vertical joint V allows the line of bars to give in the horizontal plane, as the joint *o* allows it to do in the vertical plane.

The utility of this connection has sometimes been contested, as regards running through curves, for which all that is wanted, it is said, is great enough play; beams having no other effect than reducing the drawback of the play on a straight line. This is not correct.

Connecting the two axles together tends to keep them equally well in the relative position which suits running through curves, as for a straight line; and it divides equally between them the relative displacement which makes up for the curvature. The connection by a beam has thus wrongly been found fault with by some engineers, as regards running through curves.

« This apparatus » says M. *Desgranges* (*) can only be in my view an obstacle to the running of an engine through a curve. »

But he refrains from supporting this view of the matter, which in fact would have been difficult.

Inclined planes are at the same time preferable to beams.

333. The engine of the Northern of France ran with great facility through the curves of the *Saint Gobain* line; it even managed without trouble, at a very low speed certainly, the curve of 262 feet in the yard of the works. Some details of its working under these conditions will be found in the chapter of traction up inclines. But this must only be looked on as a trial pushed to the utmost extreme, a sort of feat of which both engine and line would soon have had enough. Between the rigorous possibility of a fact, and the daily practice thereof, there is a vast difference.

If even it seems probable that an engine with four axles rigorously parallel and extreme distance of 19 ft,68, can at a low speed, carry on regular work without excessive resistances, and without accident, on curves of 900 feet and even 820 feet, it remains a question of wear and tear of rails, tyres, flanges, a question which cannot be solved either by one, or many experiments.

(*) Letter of the 21st of May 1864.

If the longitudinal displacement alone of one or several axles, controlled by a means so simple as inclined planes for example, really suffices to allow the most powerful and longest engines which have yet been constructed, to work through curves of 820 feet, and engines with six wheels coupled to work comfortably through curves of 650 feet, such is a fact of primary importance. It certainly reduces the influence of contrivances the most perfect in appearance, but the superiority of which, mainly theoretical, at least within the limits of radius in question, is far from compensating for drawbacks such as complication, loss of a portion of the adhesion, or mediocre stability.

But in spite of the good results obtained by this simple modification, combined with absolute parallelism of the axles, it cannot be regarded as a complete practical solution of the adaptation of the locomotive to curves of small radius. Under the conditions indicated just now, we are still too far from the aim towards which we must approach, if we cannot altogether attain it, that is to say : running through curves, with the same circumstances of resistance, wear, and safety with respect to running off the line, as on a straight line. However low may be, besides, the limit of 820 feet radius, for very powerful engines and with long wheel-base; of 650 feet for engines with six wheels coupled, there are circumstances which require this limit to be still lowered; where reducing the radius to 490 feet for example, instead of 650 feet would have a very great influence on economy of construction. If engines possessing the more or less complete faculty of convergence of the axles, have been adopted for lines which would do very well with parallel axles with simple longitudinal play; there are others very tortuous, for which that would not be sufficient, and which could at the same time, without drawback, sacrifice a part of the adhesion, when the inclines are moderate and the climate favourable.

CHAPTER VIII

SYSTEMS WHICH REALISE THE CONVERGENCE MORE OR LESS COMPLETELY, BUT WITH INCOMPLETE ADHESION.

§ 1. — American engines.

334. The principle is the same as for waggons (14,181), but it can only be partially accepted for engines, unless by making with radical modifications in their construction; it is in effect restricted to simply bearing axles, the others having necessarily an invariable position relatively to the cylinders, and consequently relatively to the frame.

The American engine is, then, in reality, an ordinary engine, the leading axle of which is replaced by two axles, invariably parallel, but very close together, having a small special frame, fixed to the principal frame by a turning pin, and receiving the load nearly at its centre.

The axles are thus divided into two groups able to converge, but the movable group cannot be rendered adherent by ordinary coupling. We shall soon examine into the attempts made to obtain at the same time both convergence and adhesion.

Waggons running indifferently in both directions, ought to have a transverse plan of symmetry; the pin is then placed in the centre of the figure of the truck. Engines run almost always with the truck in front; the stability is increased by placing the pin a little in front of the centre of the figure. What is an advantage for running forwards, is the reverse, it is true, for running backwards, which however is the exception; it is done besides, at a low speed.

It is clear that the engine thus arranged is far from possessing a flexibility, a faculty of running through curves, as complete as waggons.

In the latter (Pl. LXXXVII, *fig.* 42), the two turning pins o,o, are both placed on the mean curve m,m or rather on a very close parallel arc $m'm'$, in consequence of the play of the line, increased on a curve (I, 199) to facilitate the running of the flanges between the rails, and to permit the conicity to act more fully. The distance of the two trucks may be very great, without the conditions being aggravated, unless as regards the obliquity

of the coupling (326); the transverse axis MN of the vehicle is normal to the line, or at least it may be so, and one of the two groups of axles does not alter in any way the freedom of the other through in running a curve.

In engines (*fig.* 43), the two axles of the bogie, or rather their mean line *pq* may still be placed normally to the curve; the driving axle, or if there are several, their mean line *rs* can also take the radial position, but only when the distance apart of these two groups does not pass a certain limit, beyond which it would be impossible for the flanges to be contained within the rails. But even for a distance apart such that the free running through of the flanges, without tension, is possible and beyond, there is a condition which can no longer be completely fulfilled: that is the radial position of the transverse axis of the frame.

Whilst, in effect, in waggons the two turning pins are placed free on the mean curve (or on its very near parallel), in an engine, as soon as the mean line *rs* of the fixed axles is supposed radial, the longitudinal axis of the frame is placed necessarily along the tangent at A on the mean curve or more exactly along the secant α, β, and the turning pin is then out of the mean curve; the distance apart OK increases with the distance AK, and if it exceeds the half of the total play, the wheels being contained within the curve is only possible on condition that the axis AO approaches the chord of the arc, and, consequently, that its normal *rs* goes away from the radial direction. If there are three fixed axles at a greater distance apart, the movability of the bogie more necessary still than with two axles, is also less efficacious, the system yielding with more difficulty to the kind of compromise in consequence of which the turning pin approaches the mean curve, on account of a slight inclination of the mean line of the fixed axles to the radius.

The bogie receives the load, not as in waggons, on the middle of each longitudinal, but round the turning pin, that is to say in spite of the slight excentricity of the latter, in the central region on which rests a sort of cast-iron box B (Pl. LXXX, *fig.* 7; engine sent by Mr. *Grant* to the Exhibition of 1867), receiving on the top the smoke box, and laterally the cylinders. This concentration of the load on the mean region of the truck is very favourable to the constancy of the distribution between its four or six wheels; this distribution is not sensibly affected by the unevenness of the line, and the inclinations imparted thereby to the truck. As, besides, the fixed axles, generally two in number, are almost always connected together by compensating beams, all the suspended weight is found, in reality, installed

on three resting points only, and the invariability of the distribution extends to all the wheels.

The frame always inside, has very different functions and is consequently very differently arranged, to that of European engines. It is intended only in view of the transmission of the longitudinal efforts, of the invariability of the distance between centres. It does not fulfill as with us, the functions of the general base of support, requiring great stiffness vertically; thus it is reduced, on each side (*fig.* 7) to two flat bars, which fasten the guard plates of the parallel axles, solidly together, and transmit the load to the springs. At the same time we find in engines coming out of European works-shops, the large longitudinals cut off, in use in engines with parallel axles (Pl.LXXV, *figs.* 4 and 5; Pl. LXXX, *figs.* 1, 3 and 9).

The American engine is not suitable, in general, for high speeds, even on a good line, in consequence of the small load on the bogie, and of its oscillations round the turning pin, the effects of oscillations which are aggravated, if the conicity of the wheels is considerable; and on railways with very sharp curves, it reaches to $\frac{1}{7}$. Without doubt, these curves ought to be run through at a very reduced speed, but with such engines high speed is prohibited, even on a straight line. The freedom of oscillation of the bogie round the turning pin, may besides be restrained by a greater distance apart of its axles, by the application of the load not towards its centre, but on the longitudinals themselves, and on plates with inclined planes.

For low speeds, the American type gives rise to a grave objection: its incomplete adhesion. This drawback can only be diminished by bringing the bogie towards the front, in order to diminish its load; and still this is at the expense of stability by the very fact, and also at the expense of the flexibility on a curve, the inscription being forced, as we have seen, whenever the turning pin is too far away from the fixed axles. It is thus essentially an engine for moderate speeds.

The instability at a high speed, the insufficience of the adhesion at a low speed, are then the ordinary faults of this system. They are serious, but its simplicity partly compensates for them. Such as it is in America, or slightly modified in its details, this engine has rendered and renders still great services, not only in the United States, where it is well suited to the conditions of the permanent way and to the working of the lines, but also to divers European railways. Belgium adopted it for the very tortuous section of the *Vesdre*, Austria for the sections with small curves and heavy gradients of the line from *Vienna* to *Trieste;* England, for the *Lickey Incline*, a gradient of one in 39, on the railway from *Birmingham* to *Glou-*

cester, afterwards with greater reason, for the small very rough lines, of Wales and where it is still at work; and recently on the *North London*, where it forms a notable part of the stock, and even on great lines (335); in Italy, it runs between *Pontedecimo*, at the foot of the Giovi incline, and *Genoa*.

335. *Details of several engines of the American type.* — 1. Engines of the *North London*. This small line which connects the *London* and *North Western* to the *Great Eastern*, is, including its branches, 20 miles in length. Its traffic is enormous; it already had, in 1867, fifty three engines, that is 2 loc, 65 per mile.

These engines have four wheels coupled, one pair of which is behind the fire-box, and compensating beams; the load is brought onto the bogie, by the intermedium of a large bearing in india-rubber placed between two cast iron discs which spreads the pressures, and yields to the oscillations, and to the inclinations of the bogie.

Neilson and Co of *Glasgow* have constructed engines of nearly identical general arrangement, for the *Grand Trunk* railway of Canada, according to the designs of Mr *R. Eaton*, locomotive engineer. The coupled wheels are 5 ft, 08 in diameter and those of the truck 2 ft, 50.

Heating surface.... { fire-box...... 97,92 / tubes........ 923,46 } 1.021,38 sq. ft.
Effective pressure : 10 atmospheres.
Pistons : 1 ft,41 × 2 ft,00.
Weight empty : 28 tns,5; full : 32 { load on the truck.. 12 tns. / adherent weight... 20 »

The truck is formed of two light outside beams, of wrought iron, connected together by a large beam of wood 0 ft, 92 × 0 ft, 82 strengthened by iron work, and supporting a cast iron cross beam which takes the turning pin.

The longitudinals are riveted directly onto the axle boxes. The truck is thus not suspended; it receives the load by the intermedium of the block of india-rubber which is 0 ft, 59 in diameter and the same in thickness. Other small blocks placed between the ends of the wooden beam and of the cast iron cross beam only receive load accidentally.

The cylinders are outside and inclined to $\frac{1}{13}$.

Engines constructed by *Fox Walker and Co* of *Bristol* for the line from *Windsor* to *Annapolis* (Nova Scotia) where they work passenger trains and light goods trains, present several peculiar arrangements. The line

in question has very sharp curves and stiff gradients; flexibility and a great deal of adhesion are both wanted together. A ballast piece of cast iron placed behind increases the load of the four coupled wheels of 4 ft, 93, with springs connected by a compensating beam; as to flexibility, the truck with four wheels of 2 ft, 50 in diameter, has besides the radial movement a transverse play of 0 ft, 25 given to the pin, and which facilitates the inscription of the wheels in the curves, but by aggravating inevitably the want of stability on a straight line. The total base is 20 ft, 24 in length.

The Central Pennsylvania railway which has near *Altoona*, a great length on curves of 600 feet radius, and a very considerable traffic, uses engines with six wheels coupled with a bogie, ten wheels in all. The first pair of coupled wheels has no flanges, the second has very thin ones; both have very wide tyres; the third pair only has thick flanges which fit in between the rails without any play, on a straight line. This system yields, as we may conceive, easily enough to the inflexions of the line, which only act in reality on its two extremities, the bogie and the last axle.

We have already (331) found fault with the suppression of flanges. It is desirable that all the wheels should be utilised for guiding the engine and keeping it on the line. It is a great deal more logical to keep the flanges, allowing the axles to travel transversally to the line, and regulating this freedom as we have seen (333). Thus large tyres, without conicity, are avoided, required on sharp curves and with great distances between axles, for wheels which cannot displace themselves under the action of the outside rail.

The American engines already cited (334), have been working since the origin between *Genoa* and *Pontedecimo;* the articulation is rendered necessary on this section by curves of 328 feet radius on the line connecting with the port.

These engines run down to *Genoa* without being turned, that is to say tender foremost, with the bogie behind; the engine becoming thus a sort of *Engerth's* engine (350), is more stable than in running forwards.

Abandoned in Austria, American engines are still in favour in some parts of Germany, and especially on the Würtemberg line, where the whole of the arrangements adopted in the United States have been brought over in a mass, more on impulse than with reason.

Figs. 9 and 10, Pl. LXXX represent the diagram of the high speed engine constructed at *Esslingen;* it has outside cylinders, inside frames, with the hind wheels coupled, and placed behind the fire-box.

Heating surface.....	tubes : 202 of 12 ft,09 length, and 0 ft,15 outside diam.	1.016,4
	fire box..	70,6
		1.077 sq. ft.

Pistons : diam. 1 ft,43 by 2 ft,00 stroke.
Wheels coupled, diam. 6 feet.
Weight empty : 30 tns, 33.

		Tons	
Weight full................	front bogie..........	14,00	
	driving wheel.......	9,50	Compensating beam between these two.
	hind wheel..........	9,50	
Adherent weight................................		19,00	

The *Berne* State line has analogous engines, but with longer boiler, smaller wheels, and carrying their supplies (Pl. LXXX, *figs.* 1 and 2).

Heating surface.....	tubes 150; 13 ft,29 length, 0 ft,17 diam.	924 sq. ft.
	Fire box...........................	73 —
		997 —

Pistons : diam. 1 ft,34 by 2 ft,00 stroke.
Wheels coupled : diam. 5 ft,06.
Weight empty : 31 tns,50.

Weight full..........	leading bogie	16,15	40 tns,30	Water tanks. 5 tns,40
	driving axle........	12,07		Fuel do..... 3 ,00
	hind axle..........	12,07		

It is also to the same type save a still less diameter of driving wheels, that the tank engines of the line from *Lausanne* to *Berne* belong (Pl. LXXX, *fig.* 3).

336. *Engines with American bogies for high speeds.* — In England, the bogie-engine is not confined, as might be thought, to secondary lines.

Mr. *Patrick* has introduced it on one of the most important lines, the *Great Northern*, and for *expresses*. Here are the principal elements of this engine very powerful (in spite of its very ordinary amount of heating surface; but its fire-box is very great and the length of the tubes moderate), and of which figures 4 and 5, plate LXXV, represent thegeneral arrangements :

Heating surface...........	tubes...............	1.076	1.198 sq. feet.
	fire box............	122	

Pistons : diam. 1 ft,50, by 2 ft,33 stroke.

Wheels......................	bogie.................................	3 ft,94
	driving................................	8 ,07
	hind..................................	4 ,07
Length of base....................	....	21 ,94

Distribution when full......	Bogie	front wheels.........	7 tns,00
		hind................	8 ,00
	Driving wheels.........................		15 ,00
	Hind do.		8 ,05
			38 tns,05

The load on the driving axle is very considerable; but with a single pair, it is only just sufficient for such a powerful engine; if it were reduced, starting with the normal load would be difficult and slow; and it is very probable that the drivers do not fail, sometimes, to increase it still more.

It is asserted that these engines run over curves with great facility, which is quite natural; and that they are perfectly stable at high speeds, which is less evident, although that might be explained by the position of the hind wheels beyond the fire-box; by the stiffness of the *Baillie's* springs which load them; by the length of the wheel base on rails; by the distance between the axles of the bogie (6ft, 50); and especially by the fact that the load, instead of being concentrated entirely on its centre, is applied on its longitudinals, which greatly diminishes its freedom of oscillation.

It would be difficult in France to have accepted the idea of a high speed engine with a bogie frame in front. The Northern of France induced by the example of several English lines, has just now however put on the line an American bogie engine, for working express trains. It is the engine with parallel axles (Pls. XXX to XXXII), in wich the leading axle is replaced by a bogie, with the same axis; which amounts altogether to an extra weight of 4 tons.

It has been also desired, to combine together the essential character of *Crampton's* engine, that is to say the position of the driving axle behind the fire-box, with the American bogie in front. We have already cited the engine of the *Camden* and *Amboy* line, remarkable in several points, (Pl. LXXVIII, *fig.* 13). Such are also the engines constructed in 1854 at *Esslingen*, for high speed trains on the Baden Railways :

Heating surface			1.009 sq. ft.
Pistons		diam. 1 ft,33 by	1 ft,83
Diameter of driving wheels			7,00 feet
Weight full	bogie	15 tns,50	28 tns, 5.
	driving wheels	13 ,00	
Distance between extreme axles			14,30 ft.
do. axles of the bogie			4,23 «

These engines seem to perform good service; they combine however, two characteristics which ought in general to be excluded; and when a single pair of driving wheels are sufficient, it seems more logical to insure easy running through curves, to place the driving axle in the middle, giving the front axle longitudinal play, the hind axle longitudinal and convergent play, and to accept if required the overhanging fire-box, so as to reduce the distance apart of the axles, maintaining the rigorous parallelism

of those in front and in the middle. If adhesion requires two coupled axles, it might be necessary to place the hind axle beyond the fire-box, and it is of little importance then whether it is this axle or its partner which is taken for driving. Besides, as we have already remarked, it is no longer a question of the *Crampton's* type, because the presence under the body of the boiler of a pair of wheels of the same diameter as those behind no longer admits of lowering the centre of gravity, which especially characterises the *Crampton's* type (249).

What is certain, is that engines with four wheels coupled, and with American bogies, applied in the origin, to express service on the *London Chatham* and *Dover* railway have not in any way responded to the expectations of their designer. Their instability, too fully proved by frequently running off the line, was so great, that they were not allowed to take fast trains.

337. *Tank engines uith American bogie placed behind.* — It is easily conceived why the position of the American bogie properly so called, behind, is not used, in spite of certain advantages which it would present; its mode of central articulation, or nearly so, does not allow it to take in the deep fire-box of ordinary boilers; and if, besides, this obstacle did not exist, the movable truck would always have to be carried far enough from the centre of gravity for the greater part of the weight to rest on the adherent wheels; that is to say, the frame would be prolonged beyond the fire-box. Thus, this position of the bogie is only applied to engines, in which this prolongation of the frame is necesary from another motive, that is to say to tank-engines.

Such are: 1. the engines of the line from *Charing Cross to Greenwich.* They have eight wheels, the four in front coupled, of 5ft, 56 and the four behind supporting an American bogie; 2. those which Mr. *Cudworth* has constructed for the South Eastern : in these last the driving wheels on the same side are connected together by compensating beams, so that we again find here the position of matters already pointed out several times, that is to say, the principal frame supported on three points only : the middle of the intervals between the fixed axles, and the centre of the bogie.

The suspension of the latter is also provided with compensating beams.

338. *Tank engines with an American bogie at each end.* — American engines hardly ever have their wheels free; their moderate speed requires pretty considerable adhesion. If, however, the adhesion of a pair of wheels is sufficient, and if the paramount condition is great flexibility, so that the slight convergent play which can be given to the hind when it is free, is not

sufficient, nothing hinders it from being dealt with in the same manner as the front axle, that is to say replacing it also by a bogie, on condition of course of suitably lengthening the frame. Let us cite for example : the tank-engines of the line from *Bristol* to *Exeter*, constructed by *Rothwell* in 1855, and modified by Mr. *Pearson.* The cylinders and the frames are inside, the driving wheels are 8ft, 86 in diameter; and the eight wheels of the bogies 4ft, 00. These have conical tyres, but those of the driving wheels are cylindrical. They have no counterbalance weights.

The frame has four points of support: the two axle boxes of the driving wheels, and the centres of the two bogies. There have also been arranged, but with play, ultimate bearings of the principal longitudinals, on those of each truck; these are intended only to limit their relative vertical displacements.

§ II. — Engine with Bissel's truck and its derivations.

339. The imperfection of the American bogie properly so called, as regards the facility of running and the freedom of movement through curves (334), can be avoided by a suitable position of the turning pin. In order that the two groups of wheels may place themselves with equal freedom on curves, each axle having its centre almost on the axis of the line, (Pl. LXXXVII, *fig.* 44), it is necessary and it evidently suffices, d, d', d'', being the distances between centres that the position of the turning pin I should be determined by the condition :

$$(d+x)x=(d''+d'-x)(d'-x); \quad \text{whence} \quad x=\frac{d'(d'+d'')}{d+2d'+d''}. \tag{1}$$

The movable bogie can thus only have a single axle; in this case,

$$d''=0, \quad \text{and} \quad x=\frac{d'^2}{d+2d'},$$

If there is also only a single axle fixed invariably to the frame,

$$d=0, \quad \text{and} \quad x=\frac{d'}{2}.$$

It is this that constitutes *Bissel's* truck, with two axles or with one only. *Engerth's* arrangement (350) is nothing else but the application of the same principle to a movable truck with two or three axles, placed behind the engine.

340. *Combination of Bissel's truck, and inside turning pin.* — It is not always easy, nor always possible, to give the pivot the theoretical position (339); but this position ceases to be a necessary condition for free run-

ning through curves, if the outside or *Bissel's* articulation, is combined with inside articulation, that is to say, the turning pin of the American bogie. This is no longer connected to the frame directly, but by the intermedium of a rod, oscillating round a pivot fixed in the longitudinal axis of the engine; at the same time that the bogie turning round the pin takes the radial position, the pin itself turns round the articulation of the rod and brings the middle of the axles on to the mean curve.

The articulation I (Pl. LXXXVII, *fig.* 45) can then be placed either in front, or behind the group of movable axles, and at an optional distance from its centre; only the length oI of the rod must be sufficient to limit its obliquities. The position in front of the articulation is more favourable to stability, the bogie being drawn instead of being pushed; but it all depends on the position of the truck, brought over more or less towards the front of the engine.

The boiler rests by the intermedium of well fitted plates, on the rod oI, which itself transmits the load to the bogie, by the turning pin o suitably enlarged (*fig.* 46). The rod can take the load P either on the right of the pin, or at a certain distance from the axis thereof and on the side opposite to the articulation I, which has the effect of increasing, for the same deviation of the rod, the amplitude of the sliding on the plates.

The load on these latter being P, the pivot I supports $P\frac{d}{l}$, and the turning pin o, $P\left(\frac{l+d}{l}\right)$.

A stirrup e in which an appendage of the rod is inserted, stops the boiler from getting free, by uplifting, of the bogie, under the influence of the vertical oscillations of the engine.

To restrain the oscillations abnormal of the rod and the bogie, the first must not be able to take an inclination to the axis of the engine, without overcoming sufficient reactions to hinder this deviation from being produced on a straight line, and to get rid of it as soon as the engine passes from a curve on to a straight line. This condition is fulfilled by the contrivance now generally used (332) for regulating the longitudinal displacement of parallel axles, that is to say by the profile with contrary inclinations of the plates, on which is effected the relative sliding of the boiler and of the rod.

341. *Example.* — *Vaessen's engines.* — The double articulation in question has been applied to tank engines on the line from *Santander* to

Alar del Rey (Spain), which presents at the crossing the Pyrenees numerous curves of 1.000 feet, and some even of 650 feet radius.

The goods engines (Pls. LXIII, LXIV) have six wheels coupled, or ten altogether :

Heating surface.....	tubes (200).	1.393	1.492 sq. ft.	Max. press. : 8 ats.
	fire-box....	99		

Pistons : 18 inches × 24 inches stroke.

Coupled wheels, 3,94 feet. Wheels-base, 18,43 feet.

Weight.................	engine empty.........	36,5	tons
	engine full...........	46,0	»
	maximum adhesion....	37,0	»

The water tank and coal bunkers, are placed laterally.

One of the three coupled axles has a slight longitudinal play. It was at first the middle one, the front one being the driving axle; but in the engines afterwards constructed, it was preferred to give the play to the hind axle ; a preference justified in this case, the engine being guided and its deviation prepared by the bogie, and the centripetal displacement of the hind axle concurring with that of the bogie to compensate for the versed sine of the arc. The distance apart of the coupled axles is besides only 8 ft, 53 or 9 ft, 84, according to the type, for a length over buffers of 35 feet.

The turning pin o is placed at $\frac{3}{4}$ of the length of the rod, measured between the articulation I and the middle of the plates p, p. To make this rod Io (Pl. LXIV, *figs.* 1, 2, 3) take a position oblique to the axis of the engine, the outside rail ought to exert on the two flanges a pressure equal to the sum of the friction and of the component, parallel to the inclined planes, of the pressure which they support. The load on the rails of the bogie is 9 tons; as it weighs itself 3 tons, the pressure on the turning pin o is 6 tons, resulting from 4 tons, 50 on the plates with planes inclined to $\frac{1}{10}$ p, p, and of 1 ton, 50 on the pivot I. The necessary effort to produce the lateral displacement is then: $4{,}50\ (f + 0{,}1)$, and for $f = 0{,}18$, 1 ton, 26.

In reality, the intensity of the effort increases a little with the displacement, because of a slight excess of load which results from the action of the planes inclined to $\frac{1}{10}$; on a curve of 1.000 feet, for example, the transverse displacement of the turning pin is 0 ft, 075, and consequently that of the inclined planes $0\text{ft},075 \times \frac{4}{3} = 0\text{ft},098$; the front of the boiler would undergo, then, if the system were rigid, a slight raising of $\frac{1}{8}$ of an inch; but it is in reality, the plates which lower themselves by this quantity, bringing a slight increase of deflexion on to the springs of the bogie.

Plates LXV, LXVI, LXVII and LXVIII represent another engine of the *Vaessen* type, which the *Saint-Leonard* society exhibited at *Paris* in 1867.

Heating surface..... { fire-box... 98 ; tubes (193) 1.205 } 1.303 sq. ft. Max. press. : 9 ats.

Pistons : 18 inches × 24 inches stroke.

Coupled wheels 4,27 feet in diameter.

Distance between centres, coupled axles.			9,84 feet.
do.	end	do.	19,52 »
Contents of water tank.	34 cub. ft, 9.		
do. coal bunkers. .	13 ,4.		

Weight of engine....... { empty. 36 tons. ; full... 48 » { adherent weight.. . 37 tons. ; weight on bogie.... 11 » } }

Theoretical effort of traction : 8 tons.

As regards articulation of the bogie, this engine differs from the preceding one in two points : 1. the pivot I of the rod is in front of the turning pin o; 2. the plates with inclined faces p, p (Pl. LXVIII, *figs.* 8 and 9) are placed on the right of the pin, so that the load on the pivot I is *nil*. The same as in the preceding engine, the hind axle has play, and plates with inclined planes p', p' (Pl. LXVIII, *figs.* 5 to 7).

If the engine be considered, first on a straight line, afterwards on a curve of radius R (Pl. LXXXVII, *fig.* 47), the two fixed axles A, B, determine its position, its longitudinal axis C placing itself normally to the radius M, N, which abuts against the middle of the interval between these axles. The amplitude of the longitudinal displacement $\alpha\beta$ of the hind axle, the middle of which is placed on the mean curve, and that of the centripetal movement $\gamma\delta$ of the turning pin, are such that:

$$l=\sqrt{(2R-\alpha\beta)\times\alpha\beta},\quad m=\sqrt{(2R-\gamma\delta)\times\gamma\delta},$$

whence

$$\alpha\beta=R-\sqrt{R^2-l^2},\quad \gamma\delta=R-\sqrt{R^2-m^2}.$$

Set $l=7{,}55$ feet, $m=8{,}36$ feet.

Thence : for R = 984 ft.	$\alpha\beta$ = 0,35 inch.	$\gamma\delta$ = 0,43 inch.
850 »	0,41 »	0,52 »
656 »	0,53 »	0,64 »
492 »	0,70 »	0,86 »
328 »	1,05 »	1,30 »
262 »	1,31 »	1,60 »

The Metropolitan has engines with eight wheels coupled of 4 ft, 72 with leading *Bissel's* truck properly called (without turning pin), with four

wheels and with inclined planes. The rod is 6 ft, 66 in length, from the pivot to the centre of the truck.

342. *Engines with Bissel's truck with a single axle.* *Bissel's* truck with a single axle has been applied to engines with four wheels coupled, by M. *Hartmann*, a constructor at *Chemnitz* (Saxony), who has also introduced, as regulators, the inclined planes not known to *Bissel* (Pl. LXIII, *figs.* 2 to 4).

The slides with inclined planes p, p are placed directly under the axle and near the inside faces of the inside longitudinals l, l. The bearing springs are connected together in front by a cross compensating beam b, to which the strut e transmits the load.

Pistons	1 ft,25 by 1 ft,84
Diameter of coupled-wheels	4 ft,53

The position of the pivot I was determined (*fig.* 5) by the condition that the mean line MN of the two fixed axles, and the axle AB of the bogie should run towards the centre of the curves; that is to say that this point is placed at an equal distance from MN and from AB, whence :

$$\mathrm{IC} = \frac{1}{2}\left(\frac{5{,}08}{2} + 6{,}64\right) = 4\,\mathrm{ft}{,}59,$$

a value which differs little from the exact value of 4 ft, 26 deduced from the condition : $\mathrm{CI} = \sqrt{\alpha\mathrm{I} \times \beta\mathrm{I}}$, which places the pivot I at the meeting of the secant $\alpha\beta$ and of the tangent at C (*fig.* 7); while the first places this point (*fig.* 6) at the meeting of the tangents at K and at C.

The displacement CC′ is very nearly (*fig.* 7) :

$$\mathrm{CI} \times \alpha, \text{ and because of } \mathrm{CK} = \rho\alpha = 2\mathrm{CI}, \ \mathrm{CC'} = \frac{2\overline{\mathrm{CI}}^2}{\rho}.$$

$$\text{for } \rho\alpha = 525 \text{ feet, and } \mathrm{CI} = 4\,\mathrm{ft}{,}59, \quad \text{we have } \ \mathrm{CC'} = 0\,\mathrm{ft}{,}082.$$

Stops limit the amplitude of the displacement of the axle of each side of the mean position of the axis to 1 in,10.

A bolt B let into the strut h, and the body of which slides freely in a small groove of the plate iron frame T, T (*fig.* 4) prevents the separation of the engine and of the truck by the first lifting.

These engines run through easily, it is said, curves of 300 feet radius, although the amplitude $\frac{2\overline{\mathrm{CI}}^2}{\rho}$ of the displacement would then be 1 in, 54 instead of the limit : 1 in,10.

The application of the principle dates back in Austria to period already remote. There are on the South Austrian several old engines with bogies, having a single axle with the pin behind, but without planes inclined to the carrying surfaces. A swallow tail guide, sliding in a circular groove of the same section, fixed to the frame work, prevents separation by lifting.

This mode has been adopted by M. *Pihl* for the engines of the narrow gauge lines of Norway, constructed by *Beyer and Peacock* (*Manchester*).

Heating surface........	tubes... 377		417 sq. feet.
	fire-box. 40		
Pistons: 11 inches by 18 inches stroke.			
Wheels................	4 coupled....	3,75 feet in diameter.	
	2 Bissel truck.	2,50 »	
Distance between centres.	end axles.....	14,27 feet.	
	parallel axles.	6,27 »	
Weight of the engine with 1 tn, 36 of water, and 21 cubic feet of coal....	leading bogie wheels.	4 tns, 10	
	adherent wheels......	12 ,87	

343. *Engines with two Bissel's trucks.* — Like the American bogie (338), *Bissel's* truck can be applied to both ends of an engine. This is what Mr. *Sinclair* has done for the locomotives devoted to working branches and local traffic on the *Great Eastern*. They have eight wheels, the four intermediate of which, 5 ft, 58 in diameter, are coupled, placed in front of the fire-box, and the two extreme pairs diameter 3 ft, 57 are each connected to the frame by a rod 4 ft, 16 in length. The total wheel base is 17 ft, 32.

The slides by which the boiler rests on the trucks are provided with inclined planes. Their inclination, fixed first at $\frac{1}{6}$, was reduced afterwards in most engines to $\frac{1}{24}$ only, and the play limited by shoulders, brought from 0 ft, 083 to 0 ft, 125.

The springs of the coupled wheels are connected together by compensating beams. The engine carries its own fuel and water; the water tanks are placed under the boiler and behind. With the tanks half full, the two end axles are equally loaded; the hind one is so more than the other if they are quite full, and less so if they are empty. They contain 2 tns, 18 of water.

The engine weighs full, 38 tons, 21 tons of which are adherent; they were constructed by *Neilson and Co, Glasgow*.

Heating surface...........	fire-box............	64,60	1.040,60 sq. ft.
	tubes (143)..........	976,00	

Pistons: 15 inches × 22 inches stroke.

344. *Use of Bissel's bogie in the United States.* — Although the bogie with four wheels movable only round a very nearly central turning pin predominates in the United States, the bogie with a radial bar has also been greatly gone into there; it is met with under different forms, at times interesting, sometimes with four wheels, and oftener with two only. These applications have almost always, in the second case, a point in common : the smallness of the load supported by the movable bogie. It is often indeed only an extra piece, added to the front of an engine with parallel axles and which as regards distribution would perfectly do without supplementary points of support. The function of the movable bogie is then that of a directing truck, and quite to be compared to that of the guiding wheel of certain road engines. Experience proves in effect that this addition, while increasing the base of support, greatly improves the steadiness of the engine on sharp curves, and saves the flanges of the front wheels in a remarkable manner, for which it prepares the deviation.

Booth and Co of *San Francisco* have constructed for the service of the line from *Carson City* to the mines of *Virginia City*, which has curves of 125 feet radius, engines with four weels coupled, with *Bissel's* bogie (leading), with two wheels, of which here are the essential figures :

Heating surface	tubes	893	978 sq. feet.
	fire-box	85	
Pistons : 15,75 inches × 24 inches stroke.			
Diameter of wheels	coupled	4,00 feet.	
	Bissel's truck.	2,13 »	
Distance between centres (rigid axles)		9,58 »	
Total wheel base		15,00 »	

The engine weighs, full, 30 tons; the middle wheels have no flanges; an absence which may be justified, in this case, by the excessive sharpness of the curves and the impossibility of compensating for the versed-sine solely by longitudinal play in the axles.

Mr. *W. Hudson*, of *Paterson* (*New-Jersey*) has also applied *Bissel's* bogie with two wheels, to engines with six wheels coupled; but the load is transmitted to it (Pl. LXXXVI, *fig.* 8) by the intermedium of a compensating beam AO placed along the axis, and which rests at one end on plates with inclined planes to the right of middle of the axle, and at the other end on the middle of a transverse compensating beam B, B, connecting the springs of the first fixed axle together; the front of the boiler rests on the compensating beam AO at the middle of its length; p being the load on the

journals of the first fixed axle, that of the front bogie is evidently $\frac{p}{2}$, and the load applied by the boiler on the middle of the compensating beam is p.

The same builder has applied the principle to a tank-engine with four wheels coupled, by means of a bogie with two wheels at each end, for lines with very sharp curves.

The bogies are loaded bŷ means of compensating beams with equal arms which rest at one end on the transverse axle of the bogie and at the other are suspended to the springs of the coupled wheels. Only the arrangement which in front is that of the preceding engine, had to be modified behind; instead of being loaded by a central beam along the axis, the truck is so by two lateral compensating beams placed on each side of the fire-box, and loaded at the middle (*figs.* 9); p being the load on the journals of one of the pairs of fixed wheels, that of the conjoined truck is $\frac{p}{2}$, and if the two pairs of thus coupled wheels are equally loaded, the suspended weight is distributed : $\frac{1}{6}$ on each articulated axle, and $\frac{1}{3}$ on each coupled axle.

In these two arrangements, the bogies carry a slight load, but tley suppress the over-hanging, limit the vertical and horizontal oscillations of the engine, without increasing the rigid base, and facilitate incontestably the entering into and running through curves. Also *Baird and Co* (the old firm of *Baldwin* at *Philadelphia*) have applied the guiding bogie to eight-wheeled coupled engines (*fig.* 10) :

Diameter of these eight wheels..................................	4 ft,06
Heating surface..	1.440 sq. ft.
Pistons : 1 ft,64 stroke 2,00 feet.	
Total distance apart of the axles *Bissel* truck included.............	21,81 feet.
Total distance apart of the parallel axles............................	14 ft,67 »
Weight, full : 40 tons, of which 3 tns,60 only for the load on the rails of the two wheeled *Bissel*.	

It is a great pity that the distribution is not given; the presence of the *Bissel* truck has doubtless not the effect of over-loading the hind axle.

These engines work on the section, with gradients of one in 55, from *Nanticok Junction* to *Penobscot* (line from *Lehigh* to *Susquehanna*).

Bissel's truck was applied for the first time, in 1857, to the engines with six wheels coupled of the *New Jersey* line; the three quarters of the total weight are adherent, and thanks to the bogie, the engine with its wheel base of 22 feet runs easily through curves of 1.000 feet radius.

The *Erie* railway, with a gauge of 6,00 feet, has employed, since 1862, engines with six wheels coupled 4 ft,66 in diameter, constructed by *Danforth* and *Cooke* of *Paterson* (*New Jersey*), having in front, a *Bissel's* bogie with two wheels, with an 8 feet rod. There are no controlling inclined planes.

345. *Cases in which the three varieties of Bissel's bogies are suitable.* — Each of these three varieties of *Bissel's :* bogie with two wheels; bogie with four wheels; bogie with four wheels and central articulation (that is to say a combination of *Bissel's* system with the American system) has its own determined grounds and conditions of application.

1. If by reason of the load that the truck ought to support, a single pair of wheels is sufficient, if besides nothing opposes the pivot of the rod being placed in its theoretical position (338), the bogie with two wheels ought to be preferred, as being the simplest.

2. If the load requires four wheels, the central articulation becomes possible; but if the outside pivot can be placed at the theoretical point, there is no motive for the first articulation, useless in that case on curves, and detrimental on straight line.

3. It is thus only when, for want of space, the pivot cannot have its theoretical position, or the rod its theoretical length, that the special articulation of the truck round a turning pin is warranted. It is, for example indispensable when the pivot is placed, not between the two trucks, more or less near its theoretical position, but in front, as in *Vaessen's* engine, represented by Pl. LXV to LXVIII. The position of the pivot I in front of the bogie may be looked upon in this case as a sort of correction of the mode of coupling. A long bar TT (Pl. LXVI) which curves and passes under the two hind axles, is attached at A to a cross-tie of the longitudinals at the very centre of the engine, to which it allows great freedom of oscillation. It is not probable, that there was any correlation in the mind of the constructor, between the two details in question; but in fact, the arrangement which gives more stability to the bogie, diminishes a bad effect of coupling.

346. *Axles with radial boxes.* — Higher up (183), we have already spoken under the name of : *Riener's system*, of the arrangement by which the axle, at the same time that it displaces transversally to the frame, inclines to the axis thereof, and thus approximates more or less to the theoretical conditions of running freely through curves.

It is also applicable to locomotives; Mr *Adam* under whose name it is known in England, made investigations with this object of secondary importance however. Complete coupling of the wheels is very often indispensable for engines which work very tortuous lines; and it excludes any convergent play. We shall presently cite an unfortunate attempt made to reconcile total adhesion with radial axle-boxes.

As to the only possible application, that is to say, simply to carrying axles; we find examples thereof in England. Several tank engines of the little *Saint-Helen's* line have eight wheels; four wheels coupled at a distance apart of nine feet from axis to axis, in the middle, and, at each end, a pair loaded by radial axle-boxes.

The curved faces of the movable axle-boxes and of their fixed guides, belong, for both sides of the engine, to the same vertical cylinder, the axis of which passes through the centre of the contiguous fixed axle. The bearing springs, loaded by an outside longitudinal, are independent of the axle boxes; the latter provided with horizontal slides move under the spring.

These slides do not form inclined planes: this would however be the occasion for them.

Similar tank-engines have been constructed by the *Great Northern* for the local traffic of some sections, with sharp curves.

Radial boxes on *Adam's system* have been applied, but to the hind axles only, to engines with front wheels coupled of the *Great Northern*, and the *London Chatham* and *Dover* railways; they draw trains of 120 tons between *Hitchin* and *Ludgate Hill* and to the *Crystal Palace* by the *High Level*, running over, at the junction with the Metropolitan, a gradient of one in 36, on a curve of 300 feet radius.

Inside cylinders of 1 ft,34 × 1 ft,84; double frame. The driving wheels have inside and outside boxes.

The coupled driving wheels are 5 ft,47 in diameter, and the hind wheels 4 ft,00 in diameter; they are placed behind the fire-box, which carries the distance between centres to 16 feet.

The hind axle has a convergent play on each side of 2 ins,5; the axle boxes are guided by cylindrical surfaces, the vertical axis of which passes through the middle of the interval comprised between the hind axle and the middle of the distance apart of the two fixed axles, which gives 6 feet for radius.

The springs do not participate in this rotating movement of the axles. Their thrust pins rest on horizontal and dressed plates on the top of the axle boxes.

Weight: 39 tons, the water tank, carried almost exclusively by the hind bogie, being full; the total weight is then equally spread over the three axles. This load per axle is very considerable for engines which for a portion of their journey run at 40 miles an hour.

Their stability is however very satisfactory, and equally good, it is said, running backwards as running forwards, but on condition doubtless, that the load on the movable axle be not reduced too much by the consumption of water.

347. *Engines of the Paris-Sceaux line.* — These engines (Pl. LXXX, *fig.* 8) by their essential characteristics are very similar to those we have just cited, with two axles with radial boxes. They have as those, in the middle, two pairs of driving wheels, and at each end a bogie *a*. This bogie, the faculty of convergence of which is more complete, but dearly bought, is, according to the principle of the system, guided by a frame with four conical rollers, inclined at 45° (184).

M. *Arnoux* at first thought of renouncing the solid connection of the driving-wheels. Each of them was then keyed on a small independent axle. But to get over the dead points, the wheels had to be driven on each side of the engine, by two cylinders, the one inside and the other outside with cranks at an angle of 90 degrees. Experience proved this complication unnecessary. The inside cylinders only are kept, returning to the keying of the two wheels on to the same axle.

Distribution of the weight in the engines constructed at the Ivry *workshops in* 1860, *with* 70 *cubic feet of water in the tanks, and* 2 *tns,* 5 *of coal in the bunkers.*

Bogie	10 tns,3	43 tns, 24 of which are only adherent.
Driving axle	12 ,0	
Pair coupled......	12 ,0	
Hind bogie........	8 ,7	

The water tanks are placed laterally, over the coupled wheels; the consumption does not modify the distribution of the weight.

As we have already said (184), trucks with rollers would have been advantageously replaced by *Bissel's* trucks, or by simple American bogies.

All the tyres are of *Krupp's* cast steel. Those of the coupled wheels, without flanges, are of an enormous breadth, 0 ft, 98 in order that they may not cease to carry on curves. They are very heavy, and therefore, of course, very dear, their weight rendering their price exceptional: (10d per lb for the engines constructed in 1867). There is thus per engine £ 480 worth of tyres; let us add that their wear is limited, or at

least that it becomes necessary to readjust the guiding frame, which, without that, would lower, and cease to bear on the edges of the rails. It is a drawback the more to this system of bogie-trucks. The great breadth of the tyres is not sufficient even in the sharpest curves (80 feet); on those, lines of supplementary rails for the support of the tyres, if they were to quit the main rail which they are on, had to be placed on the inside.

The inside rail which runs alongside the exterior rail, is of course placed far enough therefrom, so as to leave quite free the passage of the guiding rollers.

In the long series of trials which he has gone through, with a perseverance not crowned with success, M. *Arnoux* also constructed an engine without guiding rollers. But the suppression of the rollers only attained the object imperfectly, which was, to render ordinary lines practicable for articulated stock. If the curves are sharp enough to require tyres of an excessive breadth, such as those of the engines already cited, that is quite sufficient to prohibit their running on ordinary lines, their passing over crossings, and particularly, the rectangular crossing with the secondary line raised (I, 334) in which the breadth of the openings is necessarily regulated according to the profil of the tyres of the normal stock. However the extent of the objection must not be exaggerated, the essential point being, in general, to insure the circulation of carrying stock, while engines can be confined to the sections with regard to which they have been constructed. The excessive breadth of the tyres could besides be avoided by simple longitudinal play (331), admissible even for driving axles, as *Beugniot's* engine proves (332, 6°). Instead of accepting a known solution for replacing the frame with the guiding rollers, M. *Arnoux* wished without doubt, to keep to the *ensemble* of his system a character of originality; he had besides, the satisfaction of renewing in the modified engine, the characteristic feature of his primitive system of articulated carriages, which had given place to the arrangement, a great deal simpler invented by his son (184). We shall not insist on this attempt; not writing the history of railways, we cannot stop on ideas although ingenious, which have had no practical sanction in the past and which doubtless are not likely to have any in the future.

CHAPTER IX.

SYSTEMS WHICH PRETENDED TO RECONCILE CONVERGENCE OF THE AXLES WITH TOTAL ADHESION.

§ I. — Coupling by means of chains or wheel gearings.

348. The simple longitudinal play of the parallel axles is sufficient within limits of distances between axes and of curves much wider than would be supposed. Without doubt the experience of *Saint-Gobain* (332) does not prove, by a long way, that an engine with six parallel axles and with a wheel base of 20 feet, can run regularly through curves of 250 feet radius. This would be to give to a sort of *feat*, a mistaken signification and bearing; and, if we wished to go farther, we should soon be brought to the reality of the matter, by the increase of resistance and wear, and especially by the frequency of running off the line.

When the Austrian engineers found themselves more than twenty years ago, face to face with the problem of the traction on the section of the Semring with curves of 625 feet, and gradients of one in 40, the division of the wheels all adherent into two groups able to converge seemed generally necessary. Out of four competitors who presented themselves at the competition opened by the Government, a single one believed it could maintain rigidity (engine *Vindobona*), and that without tempering its drawbacks by considerable longitudinal play, which was looked on, at that time, as very objectionable; the more so, as no other means was then known to control it than the longitudinals with *Baldwin's* pivot (332, 5°). The problem to solve was then this : transmit the rotatory movement from one axle, to another making a variable angle with it, ordinary coupling rods being of course kept for the axles of each group.

This problem still awaits a simple and practical solution. It has not, happily, all the importance attributed to it when it came up, or at least as represented apparently more urgent, on the occasion of the traction on the Semring. It works, in effect, under satisfactory conditions, with engines sufficiently powerful, with eight wheels, and with axles simply parallel.

More difficult conditions as regards curves, than those of the Semring would be hardly admissible on an important line. More powerful engines, and consequently with a longer base than those thereon employed, will never be indispensable whatever may be the gradients and the traffic, seeing that they can always be supplemented at the front and at the end of the train. It would however be going too far not to allow the problem of the convergence of adherent axles any practical bearing, and only to accord it a certain theoretical interest, in spite of the inevitable drawbacks which very sharp curves would present, even with engines of perfect flexibility; a complete solution would allow, when required, the radius of curvature to be lowered, or at least would decrease the troublesome effects of curves already as sharp as could be admitted, as on the Semring.

Since the competition of 1851, this question has not ceased to be studied. Although these researches have not led to new solutions, and although the type launched some years since with aid of a remarkable amount of publicity, and which its inventor Mr *Fairlie* has succeeded in introducing on several lines, be in reality, an application of principles already known and even already applied, it is not the less useful to pass in review types, remarkable in different degrees, several of which have done service, and which, taken up again and perfected, will enter perhaps, one day, more within the domain of practice at least for exceptional lines.

349. *Engine Bavaria by Maffeï of Hirschau,* near *Munich* (Pl. LXXVI, *figs.* 4 to 10). The builder of this engine did not give much scope to his inventive faculties. His ephemeral triumph at the Semring competition proved how imprudent is binding oneself by the absolute, inflexible terms of a program, and to judge of an engine by what it can do in a series of experiments made in a short period, and not by the work it can accomplish regularly during prolonged working. The *Bavaria* took the prize, because the judges of the competition had their hands tied by the letter of the program; but they knew very well that the engine to which they were awarding the prize, was not the solution of the problem, that it did not realise any progress, and that it was even, fondamentally inferior to its competitors.

The plan adopted by the builder, was an engine with four wheels coupled, with an American bogie in front; in order to utilise the total adhesion, including that of the tender, the question was to couple with the driving wheels A, B, on the one side the wheels a, a', of the bogie, on the other those of the tender t, t', t''. All these wheels were then of the same diameter; the transmission was done, as the American builder *Norris* had already done, by

Galle's chains g, g, working on projections g', g', keyed on to the middle of the two driving axles, of the second axle a of the bogie, and of the first axle t of the tender; the parallel axles in each of the three groups were of course coupled together by ordinary rods.

The coupling of the engine with the tender was at the same time rigid, in order that the distance of the middles of the axles connected together by the chain should be constant.

This was only an expedient; the transmission by a chain seems to yield well enough to the angular movements of the axles, but the want of parallelism of the toothed pulleys is destructive to the teeth d, d, and to the links themselves. This is what experience was not long in proving. Thus but shortly after its triumph, the *Bavaria* was cast aside still quite new, among the things which were.

Let us note in passing, as an imperfection of detail, the position in the same direction, of all the cranks, although it was so simple to divide them into two groups at 180° in order to diminish the disturbances due to the coupling parts (278).

The great length of the chain having an injurious influence, were it only by multiplying the chances of damage, M. *H. von Waldegg* proposed to interpose, between the two groups of convergent axles, two intermediate axles e, e' (Pl. LXXXI, *fig.* 11) as near together as possible, carrying the toothed pulleys connected by a short chain, and coupled by rods to the two axles to which they were respectively parallel; but this was at the most a simple palliative and complicated besides; the idea had no result.

Long time afterwards, M. *Livisey* proposed, instead of keying the pulleys fast on the axles, to fix them by a sort of universal joint which would permit them to remain always in the same vertical plane (256) in spite of the relative and variable inclination of the axles. Large straps, formed of vulcanised india-rubber and steel wire, ran on the broad rims of the pulleys, provided with hemispherical projections, pressing into the straps and opposing their sliding. This idea does not seem to have been followed up.

Altogether, the coupling by chain taken by M. *Maffeï* from the infancy of the art, has nothing impracticable when it is a question, as in these first trials, of parallel axles; but for convergent axles, experience rejects it absolutely.

350. M. *Engerth's engine* (Pl. LXXVII, *figs.* 1 and 2). —Like the *Bavaria*, M. *Engerth's* engine has a bogie; but instead of being in front, this bogie is behind, and takes in the fire-box, which excludes the central, or almost central turning pin. This pin is then placed at the front of the bogie and

its position on the frame is determined by the relation (338) which places, as we have seen, the two bogies, movable and fixed, in an independant position and greatly improves the conditions of inscription of the engine on a curve; these then become, in effect, almost as satisfactory as those of a waggon carried on two bogies. M. *Engerth's* bogie is nothing else than a *Bissel's* truck with four wheels, but placed behind, a position favourable to stability at a high speed, but not to smoothness on entering a curve. The hind bogie, movable relatively to the fire-box, which it incloses and holds up, has an outside frame (*l*, *l*, *fig.* 2) which leaves between its longitudinals and the boiler the necessary play for its relative movements; the driver's footplate P (*figs.* 1 and 2) is placed, either on supports riveted to the boiler, or on the longitudinals of the tender, and then it is movable relatively to the fire-box, which by the way, has no material effect within the limits in question. Projecting supports S (*fig.* 2), fixed to the sides of the fire-box and provided with socket slides, insure the bearings on the two longitudinals *l'*, *l'*, in spite of the variations of inclination of their plane, under the influence of the irregularities of the road. These longitudinals carry also, behind, fuel and water.

Up to that point, the arrangements adopted have their due grounds. If a very powerful and consequently very long boiler were wanted, if in reason of the curves, the rigid base ought to be short, the application of a second group of axles, movable relatively to the three or the two first, might be necessary, or at least useful. If, besides, the speed at which the engine ought to work does not require the adhesion of this movable bogie, conditions are arrived at analogous to those of the American engine properly so called, and preferable in many respects.

It is thus that *Engerth's* engines with four wheels coupled, have done and do still, good service on the Northern of France, for trains, the speed of which is from 35 to 40 miles an hour. While having a very short rigid base, the engine has the advantage (which however is sometimes exaggerated) of not overhanging. The *Méditerranée* has on its *Dauphiny* lines, analogous engines, save the less speed and consequently the less diameter of the wheels, left to them by the old *Dauphiné* company; and it is rather satisfied therewith.

But what M. *Engerth* sought, and such was, in effect, the problem, was an engine at the same time flexible, and with total adhesion; in order to couple the second group with the first, he could find nothing better than to imitate *Maffeï*, only eliminating the chain, which was no longer to be thought of, after the experience of the *Bavaria*, but that which was substi-

tuted for it was hardly any better. It was a toothed gearing, an arrangement already tried with the same object, and without success, by *Norris*, and by the *Rhymney* iron-company, which constructed in 1838, a locomotive supported by two trucks with four coupled wheels; the two cylinders inclined at 45 degrees drove a central shaft, which by means of toothed gearing, distributed the motion to the two inside axles of the two groups.

Toothed gearing has a primary drawback: it is anything but simple; the pinion of the driving axle a, acts on that of the driven axle b by the intermedium of a third pinion π, which brings the motion into the same direction; the shaft on which this pinion is keyed has its bearings set on two ties E, E (Pl. LXXVII, *figs*. 3 and 4), themselves supported by bearings turned down on the two conjugate axles a, b; their bearings have horizontal play sufficient for the alteration which undergoes the parallelism of the two axles on a curve, and which is slight in consequence of the small distance apart of the two pieces.

This transmission is thus complicated; it introduces considerable passive resistances, but in that lies its least fault. In spite of every care, of the use of the best cast-steel, the fractures of teeth were continual on the Semring, especially running down; when the brakes of the tender were screwed up, the effort was transmitted to the axles of the engine by the intermedium of the toothed gearing, which could not resist.

To justify the principle, the example of rolling mills was often brought forward, where in effect toothed gearings transmit great efforts, and at high speeds; but the comparison fails in one main point. In rolling mills the parallelism of the axes allows a great breadth to be given to the teeth, on which the efforts are spread in an almost uniform manner. In locomotives, the teeth tapered off, so as to give to the angular movements of the axles, are subjected to efforts concentrated on very small surfaces.

The difficulty is thus chiefly in the relative moveability of the axles; that is to say, the fact which led to gearing being tried, is precisely that which renders its application nearly impossible.

Besides, although a mode of transmission suits an apparatus relatively rougher, it does not at all follow that it is suitable for machinery requiring much more precision. Thus, the toothed gearing of the locomotives of the trial-line over Mont Cenis did not work so badly, because it was an affair, in that case, of axles invariably parallel: but however, these organs gave little satisfaction. As to those of the Semring, they were very quickly taken off, although unwillingly on the part of the inventor.

M. *Engerth's* engine has, then, remained uncompleted. It is only fit for running on curves, on condition of giving up total adhesion, and thus to be unsuitable for low speeds.

351. *Engerth's engine modified at the Creusot works.* — The engineers of the *Creusot* works believed they had much reduced this imperfection, by passing the first axle *a* (Pl. LXXVII, *fig.* 5) of the bogie from the second group to the first; let in without play between the guard plates of the principal inside frame, and coupled by rods with those parallel to it, this axle always receives, as in the original engine, the load of the movable outside frame; the latter rests, in that case, on the bearing springs which have become fixed like the axle itself, and inside the wheels like the other springs of the engine, not directly, but by the intermedium of the cross beams T, T, which slide on the roller-plates, *p*, *p*, *p*, *p* (*figs.* 6, 7, 8).

The *Engerth* engine properly so called, weighing full, with fuel and water, 56 tons, had only, the teethed gearing suppressed, an adherent weight of 39 tns, 20, which went down as low as 33 tons, when the fuel and water were consumed.

This was very unsatisfactory, certainly, for a low speed engine; but at any rate it had a certain amount of flexibility on curves.

This latter advantage was sacrificed in the *Creusot's* engine, because the number of parallel axles was carried from three to four; what then did it gain in adhesion? Next to nothing!

This singular arrangement, which rendered, like the first, the engine and tender inseparable; which rested the hind end of the boiler on the longitudinal of the tender, in order to bring a part of that weight back on to the fourth fixed axle, amounted after all to quite an insignificant increase of adhesion. The look of the engine was enough to show this. On weighing, in June 1859, one of the *Engerth-Creusot* engines of the *Northern* of France, on the *twelve tables* weighbridge at *la Chapelle* depot, in these two states: 1. joined to its tender; 2. separated therefrom, I verified that the total load on the eight adherent wheels, was nearly the same in the two cases.

A gain of 3 per cent of adhesion, such was the net product of this strange dovetailing of the engine with its tender; such is the figure to be set against a mass of drawbacks:

1. The rigidity of the system, a rigidity such that, on the Eastern of France, these engines were obliged to be prohibited from shunting;

2. The troubles of every sort involved by their getting off the line, which

they frequently did on curves; the separation of the engine and the tender, the connecting pieces of which being put out of straight and twisted, required very long and very difficult work. On the Eastern of France, the main lines were blocked up for twenty four hours on one occasion, by these almost inseparable masses, of 56 tons, come to grief across the lines.

"These accidents, " says M. *Jacqmin* (*)," were frequent enough to cause the Company to prohibit trains drawn by these engines from shunting on the road, at intermediate stations, and thus inflicting great inconvenience on the working of the traffic."

One of these engines went off behind, in the middle of the *Nancy* station, while running backwards through facing points. The torsion and the rigidity of the system were such, that it was impossible to get the wheels of the tender back on the line by the ordinary means, levers and jacks. The permanent way had to be undone, and put up under these same wheels;

3. The difficulty of shunting, the tender pushed in only one point, the turning point tending to go obliquely to the line, and thus jamming its flanges against the rails;

4. The very considerable variations of the distribution of the load, under the influence of the inequalities of the longitudinal section of the line, and of the compressibility of the permanent way, and at the passage from straight lines on to curves, where it forms a twisted surface on account of the raising of the outer rail (I, 203).

These overloads were excessive, especially for the tender.

Let us take up this point.

352. *Variations in the distribution of the load.* — We have already alluded (246) to an example of excessive and most unforeseen disturbances of distribution, recorded in an engine with only four wheels.

When the engine has more than two axles, the centres are constantly going out of line, as do the points of contact on the rails; and if the bearing springs are independent, to these differences correspond variations in the reactions of the springs, which are greater, the stiffer the springs.

So long as the speed is low, these variations follow each other slowly; there only result, for the boiler, oscillations of slight amplitude; the springs fulfil their functions under it, without its steadiness being much affected by the inequalities of the line, while the wheels follow them exactly. But the velocity increasing, the variations of the reactions of the springs under

(*) *Leçons sur les machines à vapeur*, vol. I, page 291.

the boiler are more sudden, they succeed each other more rapidly, their effects are superposed, and, especially if the boiler is installed on too short a base, they impart very great oscillations to it; its forces of inertia react then on the springs, increase still more their variations of tension, and the evil becomes thus increased by its own effects.

The influence of the state of movement is always more disturbing, but in a degree, for equal speeds, according to the type of engine. It is now only a question of the special causes of disturbance of the statical distribution, which, under the influence of the inequalities of the permanent way, are derived from the mode of connection established between the two vehicles composing the *Creusot-Engerth* engine.

An engine with eight wheels coupled having, as this latter, the two intermediate wheels of the same side loaded by one common spring, is in this respect in the same conditions as a sixwheeled engine, provided it be coupled to an independent tender; but with the dovetailing into the tender, the position of matters changes altogether.

The two parts react mutually on their respective distributions, and new causes of disturbance, inherent to the connection of the two vehicles become added to those which would affect them when separate.

Some experiments made on the six-tables weighbridge at *Nancy* give an idea of the consequences which the inequalities of the road must produce on the distribution of the weight, in the engines in question.

The hind axle *a* of the engine, and the axles *b* and *c* of the tender being placed on the scale, and balanced; then:

I. A wedge of iron 0 inch, 59 thick was placed under each of the wheels *a*.

The load of the pair of wheels *a* was increased by.....	3,61	tons.
That of the pair *b* was diminished by................	2,40	"
That of the pair *c* was increased by..................	1,18	"

II. With a similar wedge under each of the wheels *b*, the load on that pair of wheels was increased by 5 tns, 22.

III. With a similar wedge under the right hand wheel only, of the pair *b*, the increase of load on that wheel alone rose to 4 tns, 47, while that on the other wheel was diminished by 1 tn, 88.

According to this, an idea can be formed of what took place during the running of the engine, and particularly of the position the pair of wheels *b* is placed in, and that with the laudable intention of *rendering the distribution uniform!*

It is to be regretted that an eightwheeled engine with independent tender

should not have been submitted to the same trials. The disturbances would certainly have attained much less proportions. But if, under circumstances aggravated, it is true, as if on purpose, by the mutual connections of the engine and tender, such small discrepancies in level of the rolling surface, involve such disturbances in the statical distribution, it may well be conceived how considerable they must be even in well designed engines, on account of the rigidity of the springs applied to locomotives, and especially when, during running, the forces of inertia come in to aggravate the statical disturbance. It will also be conceived what service can be rendered by connecting the bearing springs by means of compensating beams : a step which is too much neglected in France.

Lastly, it must be further concluded from these facts, that the variations of the distribution, the accidental overloads on the wheels reach also very great proportions in certain very powerful engines with very long frames, and consequently with a great number of wheels, and with a great distance between extreme centres. The longer the frame, the more numerous the axles, the more sinuous is the line of contact on the rails, and of course also the line of the centres. If the line at any point offers a depression, at the moment when the middle part of the engine passes over it, the intermediate wheels withdraw themselves from the load, which is thrown almost entirely on the extreme wheels. It is the contrary which takes place if the line presents a rise.

If some trials were made, with this view, on the tenwheeled engine of the *Orléans* line (261) and the twelvewheeled ones of the *Northern* of France, great discrepances would be found, beyond doubt.

An eightwheeled engine with separate fourwheeled tender is in this respect, preferable to twelve wheels supporting one single frame, the two independent vehicles fitting better into the more or less irregular profile of the line.

The *Engerth* engine, properly so called, that is to say with movable axles in between which the fire-box goes, without being in the same position as the engine with independent tender, as regards the disturbances of distribution, escapes at any rate from the aggravations involved by the singular improvement inflicted on it in France. Its tender always helps the axles of the engine, it never overloads them.

353. *Alteration of the Engerth-Creusot engines of the Eastern of France into engines with independent tenders.* — For M. *Engerth*, it was a question of having, not a fourth axle coupled by rods, but a movable fourth axle. Whenever the course of the line is such that this axle may be rendered fixed,

like the three others, what ought to be done is to take advantage thereof to apply directly to that axle, as well as to the three others, the load which it ought definitively to bear. Seeing that on the one part parallelism was admitted, of the first four axles, forming a base long enough for the boiler, the fire-box of which may be partly or even altogether overhanging, with such a low velocity; seeing that besides the adhesion of the second group of axles was given up, what was the use of carrying the load from the hinder end of the boiler on to the tender, in order to bring it back from these on to the engine? The suppression of the articulation, of the dovetailing, that is to say the negation of the *Engerth* engine, such were the immediate consequences of the modification made at the *Creusot*. It led indeed directly to the engine with eight wheels coupled, and independent tender.

These observations, communicated (*) in June 1859 to the Eastern of France, were at once appreciated; but as well as giving up *Engerth* engines for the future, it was required to get rid of the drawbacks of the existing ones, still quite new, and of which of course use had to be made. Fortunately for the Company, they had only five and twenty.

By simply separating the engine from its tender with long frame-plates, and replacing the same by an ordinary tender, the adherent weight was not perceptibly modified; but the distribution of the weight became very defective: the hind axle being overloaded. This drawback was got rid of by the application of ballast, at the front, which brought the centre of gravity forward. In the design of an engine with eight wheels, this ballast can be got rid of, particularly by taking advantage of the faculty of putting an axle under the fire-box. In the case in question it was the necessary consequence of the separation : with a weight of 3 tns,.70 only, the distribution became very good. To get rid at this price, of the *Engerth* engine, and above all of the modified *Engerth-Creusot*, certainly was not dear.

At the time of the changing of the Eastern engines, in 1859, the application of this balance-weight was the object of violent criticism, entirely idle, for the whole question was reduced to this : the simple eightwheeled engine, is it, or is it not preferable to the strange and cumbrous machine it replaced? Indispensable in this instance, the ballast is in principle an insignificant detail, which is dispensed with if desired, when possible.

(*) Examination and transformation of the engines of the *Engerth* system, with eight wheels coupled, by M. *Couche*. *Annales des mines*, 5th series, vol. XVI (1859), page 141.

The distribution of the Eastern engines was the following:

	Empty.	Full.	
First axle	10,60	10,55	
Second	7,67	9,34	Adherent weight:
Hind	7,93	10,79	39 tns, 31.
Fourth	8,42	8,59	
Fifth	5,91	13,11	
Sixth	5,67	10,18	
	46,20	62,56	

In the engine relieved from its tender, and ballasted, the distribution became (full engine):

First axle	10,90	Adherent weight:
Second and third (joint spring)	22,78	45 tns, 48.
Fourth	11,80	

The maximum of the statical load per axle was thus reduced from 13 tns, 1 to 11 tns, 8, and the distribution, at first very unequal, approximated to uniformity: a favourable condition for the preservation of the tyres, particularly with coupled wheels.

Ballast is a corrective that there is no longer any scruple in accepting, even in a design. Thus, the eightwheeled engines of the *Méditerranée* system, have also ballast at the front, only not so heavy. The same thing occurs in the engines constructed by the *Graffenstaden* works for the Eastern; in that case, the ballast was reduced to 1 ton (259).

The alteration of the Eastern engines required the inside frame plates to be lengthened, overhanging, so as to give the fire-box the points of support it had, before the separation, on the outside frame plates of the tender. On account of the excess in width of the fire-box, these longitudinal plates had to be cranked (Pl. LXXVII, *figs.* 10 to 12 C, C), and act thus in less favourable conditions, as torsion comes into play at the crank. It suffices however to meet this by an increase in the thickness of the plate at that part (*fig.* 12).

A first engine thus uncoupled, as far back as 1859, in the *Paris* shops, answered so well, its advantages of every kind over the engine it was taken from, were so decided, that from that moment the alteration of the whole was determined on. It was expedited by the unanimous desire of the drivers, and the running-shed foremen. Thus all these articulated engines very soon disappeared.

" It is beyond doubt," said, in 1860, the locomotive engineer of the Eastern of France, M. *Vuillemin*, " that on the Eastern of France, the *Engerth* engines run harder on the road than the other engines; the drivers are una-

nimous on this point. It is equally admitted by all, that the engine uncoupled which has been running for a year, is smoother and more steady on the road than the other engines."

" To sum up" says that engineer (*), who was in the best position to pronounce on the value of the modification effected, " the suppression of the connection of the tender with the engine has produced a very appreciable improvement therein. There has resulted from the change, a new type of powerful engines with four axles, of simple construction and economical maintenance, able easily to take gross loads of from 540 to 560 tons up gradients of from one in 200 to one in 166. »

As to the counterpoise, if it was indispensable as correcting the distribution, it constitutes also a real improvement in itself.

" The addition of this counterpoise" says again M. *Vuillemin*, " has been blamed and looked upon by some engineers as a useless overload and detrimental to the engine. This opinion would be well founded if the heating-surface, the production of steam and the dimensions of the cylinders did not correspond to the increase of adhesion due to that extra weight. But the heating surface, about 2.120 square feet, and the other elements of the power, are largely sufficient for the new adhesion; and it ought to be acknowledged that the addition of this counterpoise, in addition to that part of the weight of the engine that was supported by the tender having brought up the total adhesion from 39 tns, 50 to 45 tns, 50, has served to increase by so much, the tractive power of the engine."

" The running of the uncoupled engine," says on his part, M. *Jacqmin* (**), " becomes smooth and similar to that of ordinary engines. Running off the line disappears, and the wear of the tyres is nothing out of the common. Proved on the first altered engine, the results held good on a second, on a third, and now, the twenty five engines possessed by the Company are all altered."

If the Northern of France has kept to its *Engerth* engines, it has at least renounced them in principle, and has for a long time ordered no more; they are replaced by engines with eight wheels (259) and accessorily by engines with twelve coupled wheels (262).

354. *Alteration of the Engerth's of the Semring.*—The South Austrian Company was not very long in following the example of the Eastern of France.

(*) *Annales des mines*, vol. XVII, page 459.
(**) *Des machines à vapeur*, vol. I, page 292.

The first uncoupled engine was put in service on that line in September 1861 (*); but as it was the *Engerth* properly so called, and not its pretended improvement, that had to be dealt with, a fourth fixed axle was applied behind. In this state, the load on the front axle was raised to 13 tns, 7 on account of the removal of the water tanks. These engines thus received their ballast behind, weighing 3 tons.

In this way the *Engerth* engines disappeared, even at the Semring, where they originated.

M. *Desgranges*, the locomotive engineer, who had seen these engines at work from 1859 to 1862, spoke, in his turn, the truth as regards them in these terms in 1863 (**):

" What I have thought and said, is, that the *Engerth* engine of the Semring, with water tanks over the driving wheels, variable adhesion, with no place for fuel, and weighing 18 tons per axle, was bad, inadmissible. I say further that the dovetailing of the tender with the engine is an objectionable arrangement, and one which involves considerable expense. We have more than *one hundred* engines on this system; you will certainly, then, admit that our experience on this point has some value."

More than one hundred engines! This boasted type was a costly gift for the South Austrian lines, all the more from having been kept working during several years, from 1853 to 1861. Now,

" It did not require long," says the same engineer, " to become aware that engines established under such conditions, were the most trying possible for the working of the line."

This is the distribution of their weight (***):

GOODS ENGINES (3 ft, 5 wheels).

	1. *The gear-work removed.*		2. *With the gear-work.*	
First axle	13,70	Adhesion : 37,50	15,25	
Second »	12,05		10,70	
Third »	11,75		15,65	
Fourth »	3,50	21,50	6,25	
Fifth »	18,00		19,80	
		59 tns,00	67 tns,65	Nominal weight

(*) *Perdonnet, traité élémentaire des chemins de fer*, t. III, p. 117.

(**) *Note on the working of the Semring, Reply to M. Flachat*, 1863.

(***) *Desgranges. Noteon the working of the Semring from* 1860 *to* 1863. *Mémoires de la Société des ingénieurs civils*. Pamphlet in-8°, 1864, page 4.

With such a starting point, what figures would be reached during the running of these engines, under the influence of the causes which come in to add, as we have seen (272 and following) in such large proportions, to the inequalities of the statical distribution?

Engine uncoupled from the tender, with 3 tons of ballast.

First axle	12,00	Adherent weight: 46,40
Second »	11,35	
Hind »	11,30	
Fourth »	11,75	
First axle of the tender	9,00	19,60
Second » »	10,60	
		66,00 tons.

The engine not uncoupled was weighed with the tanks full of water; in running its adherent weight falls from 37 tns, 50 to 33 tons. In the altered engine, this weight always keeps at 46 tns, 40.

To improve the distribution of the first a little, the fuel was reduced from 4 to 3 tons; the distribution then became:

First axle	13,50	Adherent weight: 37,25
Second »	12,00	
Hind »	11,75	
Fourth »	4,50	
Fifth »	15,25	
	57,00 tons	

The overload on the 5th axle was diminished, but was still excessive.

As to the passenger engines which only differ from the goods by the diameter of the wheels, and which could not be changed, on account of this diameter, the distribution of their weight is less objectionable, but still very bad:

First axle	13,00	Adherent weight: 36,90 tons.
Second »	11,90	
Hind »	12,00	
Fourth »	6,70	
Fifth »	12,80	
	56,40 tons.	

60

§ II. — Transmission, without gearing, of rotation between two groups of convergent axles.

355. *Steierdorf engine.* — The problem which M. *Engerth* had endeavoured to solve, the total adhesion of an engine having two groups of axles with the power of converging, has greatly engaged the attention of engineers and engine builders. By some, the solution has been sought for in the transmitting machinery; the others, making a radical change, kept the evaporating apparatus in one, and divided the driving machinery into two, each solidly attached to one of the two groups of axles; which amounts to two distinct engines with one single boiler.

The first principle has been realised only in the *Steierdorf* engine; the mode of transmission is due to M. *P. Fink*, engineer of the Austrian State lines. (Pl. LXXV, *figs.* 1 to 3, and 10 to 9).

The two trucks, both with outside frames, are connected by a joint O. The fire-box rests on the longitudinals of the tender, not in this case by lateral supports, but by the intermedium of a lower cross beam T, T, stirrup shaped, carrying a fixed roller G (*figs.* 1 and 2).

The transmission of the motion from the last axle A of the driving truck, to the first B of the other is effected by means of an axle C, receiving the motion from A by the rod l, and transmitting it to B by the rod n. The intermediate shaft is carried by two bars p, p (*fig.* 3) which rest on the axle B; they are held by guides fixed to the longitudinals of the tender, and can oscillate round their lower extremity. The distance between the points B and C is invariable, as is that between the points C and A, tied together by the rod t; but the distance between the points B and A is variable; it increases if the bar p inclines towards A, and diminishes if that bar inclines the contrary way. On a straight line, the axles B, C, are parallel, and the two bars vertical; on a curve, the latter incline in opposite directions; the distance A, B increases on the side of the exterior arc, diminishes on the side of the interior arc, and that by the action of the rails on the flanges of the wheels of axle B, which yields freely thereto, in spite of its double connection with the axle A, and places itself very nearly at right axles to the curve.

While leaving B quite free to move, this connection insures the transmission of the movement of rotation from A to B, since the cranks Am and Br are always parallel, in spite of the changes in the position of the two trucks to each other.

The axis C, always horizontal and parallel to A, lowers more and deviates further from parallelism with B, the sharper the curve is.

The solution is ingenious, undoubtedly; but it is not rigorously geometrical. In order for it to be so, the parts forming the connection between the axles and the intermediate shaft, should be in one and the same vertical plane; and from their juxtaposition results necessarily a defect which can not be neglected in practice. M. *Fink* himself states (*) that if the transmission is irreproachable on a straight line (that is to say, when this complicated machinery has nothing to do), the length of the rods would vary a little on a curve, with the angle between the axles of the two groups; for the maximum angle, the error is only 0,0071 of an inch for the rods l, but it reaches to 0,043 of an inch for the short rods n; although these differences are slight, they nevertheless develop great strains. Hence the necessity, in order to prevent breakages, of giving the parts dimensions apparently excessive, and out of proportion with those which their useful work would warrant.

In spite of the active influences interested in its success, this engine has not managed to get taken up.

The *Steierdorf* has twice figured in great exhibitions : at *London* in 1862, at *Paris* in 1867, without gaining over, it can be said, one single engineer to its principle. The general impression, unfavourable at *London*, was not less so at *Paris*, where the engine presented one modification. The hind axle was, at the outset, much too heavily loaded; it was necessary to bring it down to a maximum of 9 tns, 5, to relieve the tender of all the supply of water, which was placed in tanks placed under the van, and containing 1.200 gallons. Only the fuel was kept on the tender. The engine is thus no longer a tank-engine with total adhesion, seeing that it requires the aid of a non adherent vehicle. It would not of course do, to impute to the principle what is only the consequence of a local fact, the slightness of the rails; but assuredly no one participated in the satisfaction expressed by the engineers of the State railways, in the following statement : " the problem of the construction of a locomotive with independent trucks, and in spite of that, with all the wheels coupled, has received a practical solution in the *Steierdorf* engine; the principal difficulty of working mountain lines is thus surmounted (**) ". If such be the case, this solution, of such value, must be singularly unappreciated, for it draws attention nowhere, either for lines with

(*) *Description de la locomotive de montagne Steierdorf.* Pamphlet in-4°. *Vienne,* 1867, page 7.
(**) Ditto.

steep gradients and sharp curves, any more than the others. There are altogether three engines of this type: all three belong to the railways under the direction of its persevering promotor; and those who desire to examine the three engines should seek them rather in the repairing shops than at the head of trains.

The *Steierdorf* has without any doubt extremely considerable passive resistances. All fancy for it would be readily dispelled by verifying its consumption of fuel, running by itself, without any train (*).

The following are its principal elements:

Heating surface...........	tubes........	1245,31 sq. ft.	1323,03 sq. ft.
	Fire-box......	77,72 —	

Pistons : 18,11; inches diam. : 25,00 inches stroke.

Distribution : engine filled and with supplies.

First axle........	9,20	Adherent weight : 42,40 tons.
Second »	9,10	
Hind »	8,75	
Fourth »	6,25	
Fifth »	9,10	
Van »	15,20	
	57,60	

The two other engines, *Krassova* and *Gerliste*, only differ from the first by a simple detail. The bars *p*, *p*, which carry the intermediate shaft, and which are placed inside the longitudinals in the *Steierdorf* (*figs.* 2 and 3) are placed outside in the others (*figs.* 9 and 10), allowing the same width to be to both engine and tender frames. Moreover, bringing the tie rods and the coupling rods close together, reduces the disadvantage resulting from their being apart.

356. *Intermediate shaft oscillating in a vertical plane.* — M. *Kirchweger*, locomotive engineer of the Hanover railways, has proposed a mode of connection also founded on the adoption of an intermediate shaft; but the latter, kept in place by the ties *t*, *t*, at equal and constant distances from the two axles A, B to be connected, compensates for the variations in the distance apart of their extremities by an up and down movement, instead of compensating therefor by a horizontal oscillation (Pl. LXXV, *fig.* 11). The inter-

(*) At the *Paris* Exhibition, I asked to have these trials made; lest the examination of the locomotives by the jury did not include observations during running, which would have been however very readily made, the exhibition being connected with the Ceinture railway, by a line of rails. There was only one thing wanting : a little more confidence in the result, on the part of those interested.

mediate shaft lowering on the side of the exterior arc and rising on the side of the interior arc, the horizontal projection of the rods *t*, *t*, increases towards the first and diminishes towards the second.

The inclinations of the intermediate shaft were determined by a wedge-mechanism, the working of which was difficult to regulate. Therefore the inventor himself has given it up. Similarly with respect to a variation (*fig.* 12), in which the rods were replaced by a second system of rods and cranks, symmetrical with the first, and insuring as did the rods, the invariability of the distances C A, C B.

357. *Oscillating levers.* — Late M. *Rarchaert* and M. *Gouin* have endeavoured, each in his own way to carry out an idea, which at first sight seems easy to realise. Instead of taking for intermediate, between the two axles, a shaft connected with the two others by means of jointed rods, they transmit the rotation from one shaft to the other by means of beams *b*, oscillating round in a vertical plane (Pl. 56, *fig.* 11). On a straight line, the mean position which the beams oscillate when the axles make one turn, is vertical on each side of the engine. On a curve, this mean position is inclined on one side of the vertical (b') for one of the sides of the engine, on the opposite side (b'') for the other, which makes up for the difference in the lengths of the interior and exterior arcs A B.

The half length of the levers *b* should considerably exceed that of the cranks, the excess being great enough for the total amplitude of the oscillation corresponding to half-a-turn of the wheel not to be exaggerated.

This is a drawback; but there are plenty of others, and more serious. Unless it were attached to the frame only at its centre by a turning pin, an axle can not be driven excepting on the condition of an invariable position (unless, if wished, with a longitudinal play) with respect to the frame, on which it acts through the guard plates. Two groups of adherent axles, able to converge, thus imply two distinct frames connected by a joint; and it will be readily seen (*), that the transmission of the efforts from one group of axles to the other by oscillating levers, and the passage of the dead points, require very complicated arrangements, that is to say on the plan adopted by M. *Rarchaert* (*fig.* 12): 1st. the mobility round the turning pin I of the

(*) *Articulated locomotive with* 12 *wheels coupled,* description by M. *Rarchaert. Annales des mines,* 6th series, vol. IV, p. 91. Report to the Minister of Public Works on M. *Rarchaert's* engine by a committee composed of MM. *Avril, Mary* and *Busche,* inspectors general of the *Ponts et Chaussées* and M. *Couche,* secretary. Page 69.

horizontal shaft K which carries the beams; 2nd. the necessity of keying on to the extreme axles of each group, the right and left hand cranks parallel, and not at 90 degrees, as usually done; 3d. hence the necessity, in order to get over the dead points, to double the whole system of the connection between the two extreme axles: cranks, rods, oscillating levers, placing of course the second system of cranks at right angle to the first. For that the pins must be lengthened by a double crank, an arrangement already applied to different engines, for example in *Crampton's*, but only for the valve gear, and in *Haswell's* (228).

It is evident that the double connecting apparatus is necessary only for the two extreme axles A, B, and that for the other axles of each group, simple cranks keyed on right and left at 90 degrees, are sufficient, on the condition of establishing in a suitable manner, the connection between the double cranks of the first axle of each group, and the simple cranks of the second.

It all comes to placing the coupling rod, on one side of the engine, on to the crank of one system, and on the other side, to the crank belonging to the system at right angles. But it results from this, that the planes in which the two coupling rods work, are not exactly at the same distance from the longitudinal axis of the engine.

358. *Axles connected together at the middle. Passage of the dead points by means of a triangular rod.* — It would however be superfluous to dwell longer on an idea which is specious doubtless, but the carrying out of which presents, as we see, great difficulties, if not indeed downright impossibilities. Having converging axles to deal with, it seems very difficult to effect the transmission at two points. It is one only, consequently the middle one, that must be acted on, but insuring the passage of the dead points; and this is done by having recourse to an intermediate shaft.

This solution appears to have been pointed out for the first time by the engineers of the *Maffei* works at *Hirschau*, in the investigations arising from the Semring competition (349). The question was to utilise the adhesion of the leading bogie of an American engine; an intermediate shaft C (Pl. LXXXVI, *fig.* 13) was installed on the frame of the engine and exactly above the turning pin I, so that its middle was at obviously constant distances from the centres of A and B. Like all fixed axles, it was driven by two cranks keyed on to it at 90 degrees, and transmitted the movement to each of the axles A and B by means of a central rod (b, b') and cranks. To get over the dead points, it was sufficient to couple A and B by a third rod b'' taking on to the same cranks. In the position no. 2 for example, C

cannot determine the rotation of B directly by the action of the rod b', but by the intermedium of A, which drives B by the rod b''.

M. *Rarchaert* carried out an application of this principle to a model (*figs.* 14 and 15) : an intermediate shaft C with two rectangular cranks m, m' driven by the pistons, distributes the movement by means of central rods b, b' to the two opposite axles A, B of the two converging groups, which axles were themselves connected by a third rod b'' (*fig.* 14).

To sum up, it will be seen that the three axles are connected at their centres by a triangular rod; each of the axles A, B is driven by two rods; when the one is at the dead point, the other acts. The driving shaft C thus drives by means of the other axle and the two other rods, that on which it has no direct action.

A solution founded exactly on the same contrivance for passing the dead points, was proposed by Messrs *W. Dredge* and *A. Stein* (*fig.* 16). Only as in the *Engerth* engines, it is one of the axles of one of the groups which receives the movement of the pistons and transmits it to the other group. The shaft c is thus only intermediate, as in the *Steierdorf* engine. The two axles A, B are coupled at their centres by the rod b'', with spherical bearings. The auxiliary cranked shaft c is installed on a double frame e, e, which itself rests on the axles, on each side of and close to the cranks, that is to say of the centres, so that a very slight play of the bearings q, q, q, is sufficient to give the axles A, B perfect freedom of convergence. The crank shaft pin c is connected by a rod b, b' to each of the ends of the coupling rod b''. If A be the driving axle, it cannot in the position shown, drive the axle B directly by the connecting-rod b'', but drives that axle by means of the rod b, and the auxiliary shaft c, which transmits the movement to B, by the rod b'.

The rods b, b' only work, besides, when the dead point has to be started on, inertia being sufficient during running to get over it, and to reach the position in which the effective action of the principal rod b'' commences.

Of course advantage ought to be taken of the independence of the two groups of axles, to place their outside coupling rods at 180°; so that these cranks and their rods balance each other, and for zigzag motion as well as recoil as the system of pieces act in the same plan (Pl. LXXXVI, *fig.* 17).

359. *M. Roy's engine.* — Some years ago, M. *Roy* proposed a so termed solution which could and should have been condemned *a priori*, in all conscience. It would be very useless to dwell on this, had the project not been carried out. But the engine having been constructed, thanks to a patronage

then all powerful, and submitted to lengthened trials, it is as well to speak of it, were it only to prevent the renewal of attempts which can only end in expenditure thrown away, and complete failure.

This engine had four axles: two intermediate, parallel and coupled, driven by outside cylinders, and two extreme ones with radial axle boxes, connected each with the adjacent driving axle, by means of central cranks and a central rod. Theoretically, such an engine is not in a position to start when the central cranks are at the dead point; and if, in fact, thanks to the small play of the rod on the crank, the effort transmitted to the extreme axle by the driving axle, which has, itself, no dead point, has a leverage and a moment sufficient to determine the rotation, there are as many chances that that rotation may be in a contrary direction to that of the driving axle, as in the same direction. Starting, difficult in the second case, is impossible in the first. This fact of the *rods crossing* frequently occurred during the continuance of the trials of the engine in question on the *Joliette* incline, at *Marseilles*; in thate state it could neither go forwards nor backwards, and could only be got over, by giving it with an engine called up for the purpose, shocks which at last decided it to start, taking advantage of a vibration in a favourable direction.

§ III. — **Engines with two bogies each carrying separate machinery.**

360. *Seraing engine.* — In this case, all the difficulties of transmission, at least those with which we have been dealing, disappear. The apparatus is composed essentially of a boiler, resting on two articulated trucks, each carrying a pair of cylinders, which take their steam from the joint boiler. It is in a word, the complete application of the principle of the American carriage, to the engine. Now, that this idea seems to find some favour in the hands of Mr *Fairlie*, it is only fair to give the merit of it to those who not only conceived it, but realised it, a very long time ago. Some engineers see in the *Fairlie* type, the engine of the *future*, especially for goods. Perhaps so. But what is quite certain is that it is also, as regards principle, the engine of the *past*.

As far back as 1832, Mr *Allen* constructed, for the South Carolina line, engines on two bogie trucks, with four wheels, of which two were driving and two smaller, simply carrying. But the cylinders were not applied to the trucks; the boiler, with central and symmetrical fire-box, had, under each of its smoke-boxes a single cylinder, driving the axle cranked in the

middle. The arrangements which must have been made for passing the dead points, are not indicated.

M. *Clark* (*) puts even as far back as 1825, the first application of the principle. Locomotives on eight wheels, divided on two trucks, worked according to him, at that period, on the *Wylam Railway*. But precise details are wanting of these first attempts; while going back only to 1851, that is to say the period of the *Semring* trial, we find two complete applications, both of them remarkable: the *Seraing*, constructed by the great establishment of that name, and the *Wiener Neustadt*, by *Günther*, which beaten at the *Semring* by the *Bavaria*, were both especially the first, superior thereto by the general conception, and by the talent with which the difficulties inseparable from their common principle had been overcome.

In the *Seraing* (Pl. LXXI and LXXII) an engine interesting by itself, and well worthy of study (above all, that, at the present time its principle so long put aside, seems now to be returned to), the symmetry is perfect; it extends even to the generating apparatus which is equivalent to two boilers put back to back, after taking away the hind plates of the two fire-boxes, placed in juxtaposition. The cylinders are inside, and brought in that case, towards the opposite extremities of the frames.

Heating surface................................	1.850 sq. ft.
Four pistons....................................	1 ft,33 × 1 ft,00
Diameter of the wheels.........................	3 ft,30
Weight of the engine filled......................	56 tns,05.

Its supplies are installed on a separate tender; the load per axle is however, still very considerable.

Frame and supports.—The double boiler is installed on two longitudinals (α', α', Pl. LXXII, *fig.* 1) 46 ft, 75 long, bolted to the extremities of two wooden transoms, and which take equally the outside angle pieces serving to support the platform which goes quite round the engine. Besides the points of support of the fire and smoke boxes, each of the barrels is fastened to the frame on each side, by three supports, u, u, u (Pls. LXXI and LXXII, *fig.* 2).

This cross section shows how the general frame α', α', which is inside, rests on the outside frames β', β' of the two bogies. Each of the longitudinal plates is double for a short length, as is seen on the cross section, by an appendage, exteri orfor the first, α'', interior for the second, β''; a sort of axle T, to the two ends of which the load is applied by the double principal longitudinal $\alpha'\alpha''$, transmits it by its middle widened out to a stud, then to the

(*) *Railway machinery*, page 3.

slide V, firmly attached to the two longitudinals β', β'' of the front truck.

The piece V is in steel, as well as the stud; it has on it circular projections accurately finished, having their centre on the axis of the turning pin, on which the stud slides, pressed by the axle T.

In order that the general frame should not separate from the bogies in the movements and jerks of the engine, the axle T has a cap fixed on both sides of the axle by a bolt τ (*figs.* 1 and 2), which passes through the stud and the sliding piece V also, and the screws of which moderately tightened, keep the parts in contact without hindering the horizontal oscillation of the truck. It is almost useless to add that the openings through which the bolts pass in the piece V, are ovalised to the extent required by the oscilla tion of the trucks round the turning pins.

The whole load is thus spread over four points of support, that is to say the bosses on the middle of the four struts T.

The pivot, or turning pin, is attached, by its two extremities, not to the principal frame, which would certainly be preferable but to the boiler, and by its centre, to the bogie. The upper extremity has a sort of cap ω, forged on a piece which catches the boiler like a girth (Pl. LXXII, *fig.* 2). The lower extremity is taken by a stout piece l, l in the form of a V, which catches the pivot by means of a dowel, and the two ends of which bent round horizontally are fixed by rivets on the bottom of the boiler (longitudinal section, Pl. LXXI, and plan Pl. LXXII). The turning pin, which besides carries nothing, is kept in place in a vertical direction, on one part by means of the boss n of the bearing, which rests on the edge of the dowel, and on the other by means of the key q (Pl. LXXI and LXXII, *fig.* 2).

The bogie takes the bearing by a dowel bored in the centre of a sort of star with six arms (Pl. LXXII, *fig.* 1); two of these radii are bolted on to the longitudinals β, β, of the truck, and the others on to two cross tie-pieces bolted also on to these longitudinals. That of the two cross tie-pieces which is the nearest to the driving axle, serves at the same time as support to a *longitudinal* tie piece g, provided with forks, which take hold by means of bearings, of the extremely short body of the cranked axle, and limit its deflections. All these details are besides perfectly intelligible, by simple inspection of the longitudinal section and plan.

The dotted line x, y, z, on the plan on both sides of the end transom of the bogie, shows the outline of the counterbalance weights intended to equilibrate the cylinders, and to bring upon the axis of the turning pin, the centre of gravity of the whole system of the bogie; the turning-pins might have had excentric positions, as in ordinary American engines, and

of course necessarily opposite in the two trucks; but this would have been to give up the symmetry of the engine, otherwise complete, and the advantages which it presents.

The delicate point of engines of this kind, is the placing of the cylinders, which are movable, in connection with the interior of the boiler for the admission of the steam, and with the chimney for exhaust. For this divers solutions have been proposed and applied. It would be premature to pronounce any opinion on their value just now, none of them having yet undergone the test of time long enough, not even in the *Seraing*, and the *Wiener Neustadt*, which have never done any regular work; but there is little doubt that this movability of the cylinders constitutes a grave objection against the very principle of the engines in question.

So as to follow rigorously the order adopted in this work, the investigation of this point should be adjourned. But it is necessary to say a few words on it now at once, so intimately is it attached to the arrangement of the engine as a vehicle. In the *Seraing*, each of the introduction pipes I leaves the box B, goes down along the cross section of the barrel on the driver's side, and arrives at the joint conduit of the two valve boxes, after three rectangular bends, K, K, K, (Pls. LXXI and LXXII, *fig.* 1). Socket pieces of stuffing bones are placed on this twisted pipe, so as to allow it to yield to the relative displacements of the cylinders and the boiler. The valve-boxes W have appendages W′ W″ cast on them, which make up for the excess of the distance between the external longitudinals β of the bogie truck over that α ′of the internal longitudinals of the general frame.

The two exhaust-pipes each end on a semi-circular orifice L. The pipe L′ is joined on by means of a socket joint on to the neck of the double opening L, L; it is kept in place above by a collar *c*, *c* which can turn on a horizontal and longitudinal axis.

It was not sufficient to give the blast-pipe the necessary flexibility; it was necessary also to so arrange its penetration into the bottom of the smoke-box, that the relative displacements, horizontal or vertical (the latter due to the inequalities of the road and to the deflections of the springs supporting the boiler), may be effected without allowing air to get into the smoke-box.

A cast iron ring, the opening in which is large enough to allow all necessary freedom for the horizontal oscillations, is bolted on to the bottom of the box. On the upper face, perfectly plain, of this ring, rests another annular piece having an angle iron section vertically, with two carefully fitted surfaces, one plane and horizontal applied on to the rim, the other vertical and cylindrical exactly taking the neck, on which comes the base of the ex-

haust pipe. In horizontal oscillations, the movable rim slides on the fixed rim without uncovering its opening. In vertical movements, the neck of the tube, works like a piston, in the cylinder formed by the movable rim.

361. *Wiener Neustadt engine.* — The essential difference between this engine (Pl. LXXVI, *figs.* 1 and 3) and the preceding, consists in the arrangement of the boiler. That of the *Wiener Neustadt*, with 1.781 square feet of heating surface, was of the ordinary form, that is to say with the fire-box at one end, which did not agree very well with the turning of the bogie at that end. The engine carrying its own supplies, weighed 61 tns, 2, nearly equally distributed, on the horizontal, between the four pairs of wheels 3 ft, 61 in diameter; the load of 15 tons, excessive enough, was increased by the displacement of the water, for the hind truck in going up inclines, and for the front truck, but less, in going down (275).

The boiler rests, as in the *Seraing*, on a general frame outside the wheels, and the longitudinals of which, on a straight line, come exactly over the frames of the bogies, also outside. The four cylinders, are outside, and are grouped together towards the middle.

The front bogie only has a turning pin O, which attaches it to the general frame by the intermedium of two similar systems of diagonal pieces *c*, *c*, *c*, *c* (*fig.* 2), the one fixed to the longitudinals of the bogie frame, the other to those of the engine frame. The whole load is brought on to the circular plates *p*, *p*, *p*, *p*, having their centre in O, and it is on these that the sliding is effected.

The hind-truck, which encompasses the fire-box, could not have a central turning pin. Neither has it, like the *Bissel* truck, an external joint, for which besides, it would have been difficult to find a place. The two cross bars one over the other are thus replaced on this side by two rows of struts E, E, with circular plates having their centre at the point K, the middle of the grate. It is by the edges of these plates turned over that the movable truck is attached to the frame, only maintaining the faculty of turning round their centre.

This mode of connection was scarcely satisfactory; the hind-truck accommodated itself badly to curves, which was attributed to faulty erection; but the difficulty of erecting was the consequence of the principle. The solid connection, in a vertical direction, of the articulated trucks and principal frame was pushed much too far. The first could not incline on the second, following the inequalities of the road: a condition necessary for avoiding excessive disturbances in the distribution of the weight, and which is well enough fulfilled in the other arrangements.

The great distance apart of the struts E, E, has for object to reduce the overhanging of the great longitudinals which carry towards their extremity the supply of fuel M (*fig.* 1). In the slides *s*, *s*, run pins fixed to the lower struts, and which limit the oscillation of the truck. It is well to remark that the general frame is better utilised in this engine that in the *Seraing*. This great frame is heavy; but adopted it should at least be made use of to withdraw the boiler from all other strains than those arising directly from the tension of the steam, and especially from the effort of traction; now in the *Seraing*, each of the turning pins, fixed by the two ends, not to the frame, as should be done, but to the boiler or at least to its supports solid with it, applies the effort to them, and the latter in their turn transmit it to the general frame. In the *Wiener-Neustadt*, the cross bars *c*, *c*, at the front, and the struts E, E behind, transmit immediately to the frame the effort of the articulated truck.

Admission and exhaust. On each side of the engine (*figs.* 1, 2 and 3), an induction pipe ends at I, on a pipe θ, θ, hung from the general frame, and provided with four small pipes *m*, *n*, *m'*, *n'*, each of which, corresponding to one of the valve-boxes, receives by a socket withstuffing-box a short horizontal tube, curved to an arc of a cercle having for centre the point O or K round which the movable truck runs.

The same arrangement is carried out for the exhaust. Above the tube θ, θ, which admits the steam into the four cylinders, runs another conduit θ', θ', equally connected with the four exit orifices M, N, M', N', by socket pipes. This conduit is prolonged as far as the smoke box, into which it enters turning up vertically.

362. *Fairlie's engines.* — Mr *Fairlie* has tried several variations, which it would be superfluous to examine. We shall therefore keep to the arrangements shown on Pl. LXXIII and LXXIV, which have been engraved from the drawings he has been good enough to send me. They contain his latest improvements. The couplings are taken on to the transoms of the two bogies, and the fixed frame only extends from one to the other of the large brass pivots π, π'. This frame supports the boiler, and conveys the efforts, traction and shock, from the first pivot to the second, which conveys them to the hind-bogie. The sliding takes place on circular plates *p*, *p* (Pl. LXXIV).

In some of his types, Mr. *Fairlie*, like M. *Krauss* (240) utilises the water-tanks as an element of the fixed frame. Two long lateral tanks, stiffened by the transoms which carry the turning-pins, and by other strengthening pieces, form a sort of cradle on which the boiler is placed. Mr. *Fairlie* ab-

solutely rejects the tender, the suppression of which is indeed one of the essential points of his program; and he gets rid of it by multiplying, in consequence, the number of wheels in each of his bogies. Admitting the principle of the double articulation, and the movability of the cylinders relatively to the boiler, one cannot but agree with Mr. *Fairlie* in this. The separate tender is the main objection which can be raised against the *Seraing*, considered by itself, and independently of the conditions of the *Semring* program. The fuel and water should have been brought on to the engine, increasing the number of axles of each bogie to three.

Plates LXXIII and LXXIV show clearly the arrangement of the jointed admission and exhaust tubes. The steam reaches the cylinders along $\alpha\beta\tau\gamma$, and it goes from the cylinders to the chimney along $\delta\theta V$. On each of these passages a short length is let in, τ for the admission, θ for the exhaust terminated at each end by a socket with spherical joint, which permits it at one and the same time, to give all the angular movements set up, and to slide in the direction of its length.

Mr *Fairlie's* different types have received for some time, only however in the way of trial it is true, pretty numerous applications, in England, the United States, and elsewhere. The following are some examples :

1. Mr *Mac Donnell*, locomotive engineer on the Great Southern and Western of Ireland, has introduced on that line, engines which belong by their general arrangement to the *Seraing* and *Fairlie* type, as they have the two articulated trucks, but one only, the first, driver, half the weight being sufficient for adhesion; the second, which carries the water tank, has smaller wheels. The load of the general frame is brought on to the trucks by a strong india-rubber cushion. The suspension-springs of the leading truck, are connected by a longitudinal compensating beam; behind, one common spring loads the two bearings, which are nearer together on account of the smaller diameter of the wheels.

The mobility of the blast pipe relatively to the cylinders is simply managed; the pipe is formed of two separate portions: the lower ones fixed to the bogie; the upper one, widened out and taking over the other like a hood, is fixed to the smoke box; the arrangement seems satisfactory enough. As to the admission pipes, it is, on account of their small diameter (3 inches), by their elasticity alone that they yield to the relative movements of the boiler and bogie.

The engine with a supply of 3 tns,6 of water and 1 tn,5 of coal, weighs 35 tns, 17, 22 tons of which on the leading bogie, and 13 tns, 17 on the other. This engine runs steadily, and passes easily through curves of 100 yards, with wheel base of 25 ft,50 on extreme, and 14 ft,50 between the axes of the

bogies. It would run easily also through curves of 66 yards if the driving wheels 5 ft, 25 in diameter did not come in contact with the frame of the fire-box. Of course, it is easy on this plan to construct an engine so as to run through any given curve.

Mr *J. Cross*, engine-builder at *St. Helen's*, delivered to the Vale of Neath railway, from *Swansea* to *Brecon* (Wales) engines weighing in running order, 48 tons, with 8 tons of water in the tanks, and which with a wheel base of 22 feet, run perfectly through curves of 57 yards.

A *Fairlie* engine (the *Little Wonder*) is running successfully on the little *Festiniog* line (I, 10).

This type has been tried on the Mid-Wales (ordinary gauge):

4 cylinders, 15 inches diam., 22 inch stroke;
8 wheels, 4,5 ft diam. Heating suıface : 1.992 sq. ft.
Boiler, diameter 4,00 feet.
Length between tube plates, 24,00 ft.
Weight full : 54 tons, including 9 tons of water and 1 tns,75 of coal.

A very considerable load for eight points of support.

Mason and Co., of *Taunton* (Massachussets) have constructed for the Great Pacific railway, engines on the same system, specially intended for the crossing of the Sierra Nevada. Although the Pacific permanent way is looked on as pretty solidly established, and these engines are in themselves lighter than the preceding, the points of support have very properly been increased.

Each truck has thus six wheels, 3 ft, 5 in diameter:

4 cylinders, 15 inches in diam, by 24 inch stroke.
Heating surface : 1.845 square feet, of which 124 square feet are direct.
Engine full, with 13 tns,6 of water in the tanks : 54 tons.

The type in question has been adopted by the engineers of the narrow gauge lines (I, 15) of Queensland, with gradients of one in 45, and curves of 109 yards radius. The engines constructed by *Neilson and Co*, *Glasgow*, have two trucks with six wheels 3 feet in diameter, the middle axes without flanges:

Cylinders 11 inches in diam., 18 inch stroke.
Weight, full : 28 tons.

The Central Venezuela railway is to have *Fairlie* engines :

One of the most powerful, constructed for the *Iquique* line (Peru), the *Hercules*, has the following elements:

Heating surface	tubes	1.495	1.620 sq. ft.
	fire-box	125	

12 wheels diameter	3 ft,30
4 pistons	1 ft,25 by 1 ft,84 stro
Water in the tanks	10 tons
Fuel in the bunkers	2 tons
Tractive effort	9 tns,05
Weight	60 tons

This engine, intended to work on an incline of which we shall treat farther on, ran easily through a small trial line at *Hatcham*, and formed of two half circles, 50 feet radius, joined by two tangents 100 feet long.

363. *MM. Meyer's engine* (Pl. LXXX, *figs.* 11, 12 and 13). — MM. *Meyer and son* have studied for several years, an engine with complete adhesion, and flexible, starting, as the engineers of the *Seraing* and Mr. Fairlie, with the principle of a single boiler supported by two bogie frames, each of them driving. An engine, *l'Avenir*, constructed from their designs, has been worked successively on the *Northern of France*, the *Saint-Gobain*, the *Neuchâtel*, and *la Chaux-de-Fond*, the *Central Swiss*, and the *Belgian Luxembourg*. It is desirable to go into some details on this engine, which is worked out in a really practical manner. Unfortunately, the designers have hitherto been able to get not one French company, to make on a line with many curves, comparative and methodical experiments sufficiently lengthened, to bring out the worth of the system from the point of view of consumption and maintenance. This indifference is to be regretted.

Let us note, without dwelling on the point, that MM. *Meyer* reject, and rightly in our opinion, the boiler with central fire-box adopted by the *Seraing* engineers and Mr. *Fairlie*, and stick to the ordinary form, which is much more convenient for attending to the fire and to the engine, and also utilises the fuel better.

On the other hand, it involves the risk of burning the roof of the fire-box; and objections may be raised to the excessive length of the tubes in a large boiler, and consequently the portion of the heating surface which is little efficient. But that is a special question which will be dealt with in its place (III, 18 and following); and which it would be premature to enter upon here.

One of the important features of this engine is the absence of any fixed frame, even partial. The two trucks take the boiler directly, as well as the tanks and coal bunker. The boiler has only three points of support: in front, a pivot placed in the mean vertical plane, in the central point on plan of the front-truck; behind, two side supports, placed on the transverse axis of the hind-truck.

These two supports are of course provided with spherical slides like the *Engerth* engine.

The hind-truck does not turn, as does the front one, round a central pivot fixed to the boiler; it is, within the limits of the carriers on their supports, independent thereof: the boiler, as in the *Fairlie* engine, in no way serving to connect the two trucks. This connection is effected by a simple coupling bar T, attaching the pivot X of the leading truck to a point K on the second, placed in front of its central point.

This second truck turns thus, on a curve, not round a fixed point on the engine, as in the *Seraing* and *Fairlie* engines, but round an articulation which itself is movable. The relative displacements of the boiler and the hind-truck are at the same time limited by the shoulders on the supports of the shoes. The coupling bar never works excepting in traction; a very slight play in its hind joint, and dead buffers o, o, placed between the two trucks, and along their longitudinal axis, insure the transmission of shocks without bringing them on to the bar. Guard chains, which, on account of the absence of elastic apparatus, and of their closeness to the longitudinal axis of the system, can only have a very slight excess of length, but which are therefore exempt from the objections pointed out farther back (131), would supplement the main coupling, at need, in the event of the bar breaking. The coupling of the train drawn is done on the hind cross-beam of the second truck, and the designers have thought well to apply *Stradal's* coupling (326), which seems to us scarcely in its place in a flexible system such as that in question, or which at least would only be justified therein by extreme sharpness of curves.

We see that the thrusts applied by the axles of the first truck against their horn-plates are transmitted by the turning pin to the connecting bar, and from that to the frame of the second truck, and to the coupling. As to the thrusts of the axles of the second truck against their plates, they are transmitted directly to the coupling by means of the frame of that truck.

The installation on three points (already applied, as has been seen, to divers engines, in a more complete manner indeed seeing that it extends to the whole suspended load, and not as in this case to the boiler only) is very favourable to the distribution of the weight. The inequalities of the road are thus no longer met only by springs of mediocre flexibility, but by the inclinations in all directions which the two independent trucks forming the base of support, can take relatively to each other.

As in Mr *Mc Donnell's* engine cited just now, the differences in the position of the cylinders relatively to the intake of the steam are made allowance for

by the elasticity of the tubes. These tubes should thus be as small and as thin as possible.

As regards the exhaust (*fig.* 13), the front pivot X is hollow, and forms the base of the blast-pipe; this base is let into the box B where the steam from the four cylinders arrives : directly, in the case of the front ones, and in the case of the hind ones, by means of tubes with socket joints.

There are two regulators, one for each truck; the screw works the two valves-motions together for reversing, but are rendered independent at will. The two pairs of pistons can thus be worked at the same notch, or at different ones. At need even, if the engine has to work on lengths with very different inclinations, one pair only can be worked, that is to say more advantageously than with the too restricted admission, which the simultaneous working of the two pairs would then necessitate.

L'*Avenir* engine has 1.636 square feet of heating surface, of which 86 square feet are for the fire-box.

The wheels are 4 ft, 27 in diameter and the distance between the axles in each group is	9,51 feet
It weighs empty	40,5 tons
d° with average of coal and water	47,6 »
d° quite full	50,5 »

Or, assuming uniformity of distribution which is not perfect in that state, 12 tns, 6 per axle. The inventors believe that the weight could, every thing else equal, be reduced still by 3 tons, although divers means of lightening have been adopted, particularly the use of cast steel plates for the boiler, 0 in, 37 thick. But we can understand that a certain reduction might be got out of the new and special portion of the apparatus. The very principle of the division of the motor into two, is, at the same time, hardly in itself favourable to lightness. An engine with long tubes and small wheels which weighs when empty, 40 tns, 5, with a heating surface of 1.636 feet, can certainly not pretend to relative lightness.

The engine ran easily through the curve of 88 yards radius at the *St. Gobain* works, but the Northern of France engine with six parallel axles had preceded it thereon (333); the *Avenir* even took a curve of 51 yards radius on the line at the *Fives-Lille* works.

As regards its effort of traction at a given speed, it is that which corresponds to its elements: heating surface, pressure in the boiler, adherent weight.

The useful work that an engine can do, with the principal elements known, and of which the boiler does not depart too far from ordinary proportions, can be very closely judged of. Any particular arrangement of the vehicle

can only have a marked influence on this useful work, by modifying the special resistances incidental to curves; it is thus only on very tortuous lines that this influence can be clearly brought out.

In order to judge of a new type, to establish its superiority over usual types, it is not sufficient to have verified that it passes more easily through curves of given radius, while at the same time possessing on a straight line, the same amount of stability at a sufficient speed. That is doubtless something, but very far from everything. The consumption of fuel must also be compared, with the same useful work; and that is a comparison, which as we know, requires pretty lengthened observations. It is necessary above everything to form an exact estimate of the influence of the new arrangements on the chances of damage during running, and on the maintenance of the engine; and for that, a long period of working is required.

The note which follows, drawn up by MM. *Meyer*, sets forth the good qualities which l'*Avenir* is said to have shown in the course of the trials on the line from *Neuchâtel* to *la Chaux-de-Fonds;* of course in reproducing the note, we make a distinction between facts and simple inferences. Let us point out only, one singular inadvertence; after estimating at 33 lbs, in the calculation of the work on the pistons, the resistance proper of the engine, in the note it is afterwards reduced to one-half, that is to say to that admitted for the waggons.

" The locomotive *l'Avenir* with two bogies with four coupled wheels 4 ft, 16 in diameter, has just been subjected to interesting experiments on the industrial line of the Jura, from *Neuchâtel* to *la Chaux-de-Fond* (Switzerland).

" It is well known that the most powerful engines, those with eight wheels coupled, only work satisfactorily at a velocity not exceeding about 13 miles an hour.

" The great rigidity, and the friction engendered by the coupling solidly together of the eight wheels of these engines, absolutely prevent them running as fast as engines six wheels coupled. It is for this reason, among others, that eightwheeled engines are rejected on English railways.

" Although quite as powerful as the heaviest engines eight wheels coupled (it draws 750 tons up one in 200; 6 to 7 tons traction at the circumference of the wheels), *l'Avenir* can however, run at the highest usual speed of engines with four wheels coupled.

" It is this that has been proved by the special experiments of which we now give an account.

" The 5th., 6th. and 7th. of January 1872, *l'Avenir* took three special trains of 53, 67, and 51 tons respectively up the inclines of one in 37, to one in 34,15 from *Neuchâtel* to *la Chaux-de-Fond* at the maximum velocity of 31 and minimum of 25 miles an hour (3,2 to 2,7 revolutions a second). On the horizontal or on flat gradients, the velocity attained was 50 miles an hour (5,4 revolutions a second).

" From *Neuchâtel* to *la Chaux-de-Fonds*, the distance is 18 miles, 15,5 of which are

on a gradient of from one in 37 to one in 34, only broken at the four stations by very short pieces of horizontal: the longest being only 50 yards. Two minutes only were allowed for the engine to get up its speed on the gradient of from one in 37 to one in 34.

"The tangential effort of traction thus exerted was 4 tns, 145, according to the following very rough calculation :

Gravity of the train, mean weight 57 tons, mean gradient one in 35,5 = 0,028	
57 × 28	1,596 tons
Resistance of the train to rolling (axle boxes with grease) 57 × 0,007	0,399 »
Gravity of the engine, 50 × 28	1,400 »
Resistance of the engine, 50 × 0,015	0,750 »
Total effort	4,145 tons

"This effort having been exerted at the speed of 25 miles an hour at least, or 36 ft, 6 a second, the work developed as a minimum was:

$$4{,}145 \times 36{,}6 \times 4 = 618 \text{ horse power}$$

of 550 foot pounds.

"As the heating surface is only 1.636 feet, out of which are only 86 feet for the firebox, each square foot of total heating surface gave then 0,38 horse power of work.

"This extraordinary amount of useful effect is about double that realised in the engines with eight wheels coupled. It is due to the multiplicity of beats from the four cylinders of *l'Avenir* into the same chimney, giving a more continuous and more efficient draught. In the *Meyer* engines, the heating surface can thus be reduced, if required, for the same amount of work to be produced.

"Altogether, with engines of this type, the ordinary speed of six wheels coupled engines, or from 18 to 25 miles an hour, may be maintained for goods trains, while at the same time the weight of the trains can be increased in the proportion of 3 to 4.

"*L'Avenir* has too small wheels to be applied normally to velocities of more than 28 miles an hour. The experiments which precede had for principal object to prove the possibility of very rapid running, with great stability, and consequently to point out that, contrary to a very widely spread error, locomotives with movable trucks can be applied to high speed trains.

"An engine of *l'Avenir* type, mounted on wheels from 5 ft,25 to 5 ft,90 in diameter, would be able to do the work of every kind, on a great line.

"It is probable that an engine with eight wheels coupled would not be able to attain, even with its tender alone, a greater velocity than about 30 miles an hour: that is to say that all the work of which it is susceptible would be found to be absorbed by its own friction at that velocity.

"At the normal velocity of from 11 to 12 miles an hour, an engine with eight wheels coupled already requires for its own translation an effort of very nearly 1 tns, 50, or 23 per cent of the maximum effort of which it is capable, or 6 tns, 50. *L'Avenir*, on the contrary, only requires an effort of 0,35 of a ton, 15 lbs, 43 per ton of its weight, or less than 6 per cent of the same total effort."

The locomotive engineer of the Central Swiss line, M. *Riggenbach*, sums up in these terms, the opinion to which he was led by the trials made on that line :

"The Central Swiss system, passing through very broken ground, has almost continuous curves, the maximum radius of which is only 285 yards, and frequent inclines, which on the length from *Olten* to *Sissach;* go as high as one in 50, one in 40, one in 38, and which occur simultaneously with the curves. On this system of lines, *l'Avenir*, at a speed of twelve miles an hour, drew the following loads :

Up one in 100,	one in 50,	one in 40
350 «	200 »	150 tons

"Altogether, I believe this system *beats all the others*, for lines with steep gradients, and with curves of small radius."

On the great Luxemburg line, l'*Avenir* taking 280 tons up gradients of one in 60, was inferior, in this respect to an ordinary engine with eight wheels of the same weight; but the latter seemed to try the permanent way very much.

364. The circumstances, in which total adhesion with great power and great flexibility are required, multiplying daily, it is quite reasonable to go back to the principle, so long put on one side, carried out in the *Seraing* and the *Wiener Neustadt*. But there should be no infatuation indulged in. Engines with two driving bogies cannot yet be properly judged of, and perhaps they have serious disappointments in store for their partisans, especially as regards maintenance. This complicated form of engine should only be had recourse to in the circumstances where it becomes preferable to the simple types, sanctioned by practice. But at what point does it really become so? That is what can only be determined by lengthened comparative trials; and perhaps the preference would be rarely accorded to it, particularly if no exaggeration is gone into as to the advantages of one single motor, and if the motive for objecting to the one motor be taken into account as it ought, that is to say the importance of having an engine behind on steep gradients.

Let us admit however, that engines with three, and, with greater reason, with four parallel axles run through curves with much more difficulty than the rolling-stock they draw; any arrangement which, without interfering with their power, permits them to be put in the same position, as regards running through curves, as carriages and waggons, is an incontestable progress, which can and ought to be put into practice. Only, like all inventors, or like all those who devote themselves to promote a particular system, Mr. *Fairlie* greatly exaggerates the extent of the applications which he can foresee; he makes out, wrongly, that he has produced a *universal*

engine. Comparing the *Fairlie's* engine to the system of two engines back to back, Mr. *W. Bridges Adams*, asks himself, and not without reason, if in the first, it is really one single boiler we have to do with. If there is only one barrel, are there not often two fire-boxes (Pl. LXXIII) and always two sets of tubes? And if there are two fire-boxes, would it not be better also to divide the shell itself into two, that is to say, have two engines back to back?

As to running through curves, if the distance between the parallel axles is the same, the conditions are equivalent, or even better, as regards stability, for the two engines, whenever the velocity is considerable. The water tanks can be arranged with equal facility in both cases. There remains the stoking of the fire, and in this the advantage is without dispute to the *twin* engines; the single boiler with its fire-box or boxes in the middle, accessible only at the sides, with the driver on one side, and the fireman on the other, is a real cause of trouble, which can be reduced only by raising the two side foot-plates, so as to separate less the two persons, one of whom is neither more nor less, so to say, than the arm of the other.

In the *Fairlie* engine, the coupling is done on the bogie trucks system, directly attached by the partial intermediate frame. If, as is the case with low-speed engines, the line of the middle of the frame is considerably above the line of centres, there is a couple $t \times h$ (277) which diminishes the load on the front-bogie, and increases by the same amount that on the hind one.

In the same way, each of the bogies is solicited by a force $\frac{t}{2}$ applied to the turning pin at the very level of the line of traction (Pl. LXXIII) and, then, by a couple $\frac{th}{2}$ tending to turn it over from front to back; the weight brought over from the front pair of wheels upon the hind pin is $\frac{th}{2d}$, d being the distance apart of the two axles. This disturbing force disappears nearly, in engines with larger wheels, the centres of which are little below the mean line and frames.

In the *Seraing*, where the effort of traction is conveyed to the train, drawn, by the general frame, and applied by each of the driving-trucks to the widened out middle portion of its turning pin, we have: $t =$ ($\frac{1}{7}$ of the weight) 8 tons; $h = 1{,}41$ feet (distance from the middle of the pin to the line of the centre of the wheels) $d = 6$ ft, 92; whence, for the displacement of load, 0 tn, 815 for each truck.

CHAPTER X.

TRACTION ON INCLINES, THE TRACTIVE EFFORT BEING TRANSMITTED SOLELY BY THE ADHESION DUE TO THE WEIGHT OF THE ENGINE.

§ I. — Preliminaries.

365. Nothing is simpler or more evident, than the immediate effect of a given incline; the increase of tractive effort involved thereby is known. Nothing is more complicated however, in reality, than the question of inclines taken as a whole: the comparison of the different traces which can be laid out between two given points, and the choice to be made between these, being often difficult and delicate operations.

Let us for a moment, abstraction made of the nature of the motor, fixed or movable, look into the influence of inclines upon the final work to be produced, simply in drawing the *useful load*.

If an incline of $\frac{1}{i}$ in length l is run over, up and down, by trains of the same weight P, and at the same velocity, to which corresponds on a level the coefficient of resistance r, the effort of traction is:

For an ascending train: $P\left(r\sqrt{1-\frac{1}{i^2}}+\frac{1}{i}\right)$, ... (1)

For a descending train: $P\left(r\sqrt{1-\frac{1}{i^2}}-\frac{1}{i}\right)$, ... (2)

And the total work is: $2Pr\sqrt{1-\frac{1}{i^2}}\times l$, ... (3)

that is to say, the same as is required to run over the double length of the horizontal projection l' of the incline; in as much as

$$l'=l\sqrt{1-\frac{1}{i^2}}.$$

But it does not follow, even in this case, that the inclines are without influence on the *total* work to be developed. The motor, whatever it may be, must in effect be capable of producing a tractive effort, greater than on a level, in the ratio

$$r\left(\sqrt{1-\frac{1}{i^2}}+\frac{1}{i}\right):r.$$

It must then be more powerful, and if a locomotive, heavier, in the same ratio.

If $\frac{1}{i} = r\sqrt{1-\frac{1}{i^2}}$ or very nearly r, (2) $= 0$, the useful work becomes $2Pr\sqrt{1-\frac{1}{i^2}}$ or nearly $2Pr$; it is exerted entirely in ascending, and the motor requires an effective power twice as great as on a level.

Beyond this, that is to say for $\frac{1}{i} > r$, the work $P\left(r + \frac{1}{i}\right)l$, always developed entirely in ascending, is $> 2Prl'$, that is to say, greater than on a horizontal. In descending, under the influence of the accelerating force $g\left(\frac{1}{i} - r\right)$, the velocity would increase until the resistance increasing therewith, attained $\frac{1}{i}$.

It is necessary then, in as much as the condition is to limit the velocity to that which corresponds to the resistance r, to bring in an additional resistance $P\left(\frac{1}{i} - r\right)$.

Thus, under the admitted conditions, inclines would modify the useful work, only when their inclination exceeded the resistance on a level corresponding to the fixed velocity.

But if these hypotheses are simple, they are very far from being realised. On the one hand, it is in no way necessary nor even expedient that the velocity should be the same on inclines as on a level; on the other, the load to be drawn is rarely the same in both directions.

For the velocity, the most favourable condition, and that which should, henceforth, as much as possible determine it at every point, is that the motor, working always at its maximum of power, should draw the same load on inclines as on a level. The velocity would therefore be, in ascending, that to which corresponds, on a level, a resistance $r' = r - \frac{1}{i}$, and this reduced velocity is possible, provided that the corresponding effort of traction does not amount to the adhesion.

As to the ratio between the weights of the trains ascending and descending, that must be taken such as it is, and it is often very different to unity.

For passengers, there are only accidental variations, and equality is always found to exist, when a long enough period is taken, a year, or even some months.

It is not the same with heavy goods, which flow from the points of pro-

duction to the points of manipulation or of consumption; it is rare that the centres of population are of nearly the same importance in these two respects. *Paris* for example, which consumes a great deal, produces much also, as regards value; but as regards bulk and tonnage, it produces far less than it consumes.

By a fortunate natural arrangement, the origin of the primary substances of industry, or the point where they are brought to light, is often at a more elevated level than the localities of manipulation and consumption, situated more especially in the valleys, so that the descending trains are much heavier than the ascending ones.

But putting aside the actual nature of the motor, leaving indeterminate an element the influence of which on the total work to be produced is always considerable and sometimes enormous, leads in reality to an analysis beside the question. A complete theory of railway inclines has neither been made, nor perhaps is able to be made. By wishing to treat in a general manner, this problem technical and economical at the same time, we find ourselves by the impossibility of bringing all the elements into account, led to create a sort of factitious mean, whence we can only logically draw consequences without practical applications.

Between two given points, several lines can in general be laid down, differing by the inclination and the length of the gradients, by the radii, length and number of the curves. Amongst these lines is one without doubt, to be preferred to all the others. Its definition is most simple: it is that which, while at the same time complying for velocity, for safety, with the conditions of its establishment, brings out the lowest total annual expenditure, construction and working. But its determination is often very difficult; it depends on an element the influence of which on the trace is predominant, that is the traffic. In the same topographical conditions, a trace good for a given circulation, may be very defective for a very different circulation. If it is very active, the maximum of economy corresponds to a costly, but relatively easy line: the working benefits by the sacrifices made for the construction. If the circulation is low, economy of construction must be above all aimed at, without fear of affecting the working of the line.

What complicates the problem still further, is, that if the traffic must often influence the trace, the latter may in its turn react on the traffic.

It is not a question, in effect, of a mass of freights absolutely and necessarily acquired by the railway, whatever may be its conditions of trace; traffic quickly deserts one line, as soon as it finds another prompter and cheaper.

At the outset, inclines were rare and flat. They were sought to be avoided, and with reason. It was generally, besides, easy to do so, the districts which were the first endowed with great lines of railway, offering facilities. But later railways were wanted every where, in spite of all obstacles; no centre of any importance would put up with isolation; railways must be made in the most difficult districts, and they were pretended to be made cheap. A condition the more desirable effectively, as these districts are often also, the least productive; but impossible to fulfil in a number of cases, even accepting for the line all the inflictions, which do not exclude absolutely the regularity and safety of the working, but tell heavily thereon.

Reduced to the local traffic, such lines cannot remunerate their capital. Their situation may improve, if they are able one day, to take part in through traffic from a distance; but that traffic avoids heavy lines as much as possible, even at the cost of a considerable round, where the traction as regards the useful weight, is very expensive.

366. *The cost of traction and notably of fuel per train mile, is the less, the heavier the line.* — A confusion is occasionally made on this point against which it is well to warn the reader at once. The expense of traction and especially of the fuel per train mile by a given engine, is so much less, for the same difference of level between the two extreme points, as the line is heavier; and that for the simple reason that the engine, the load of which is ruled by the rising gradients, and which consumes fuel thereon in consequence, consumes less, and even none at all on the heavy down inclines. The cost of the train-mile is the less the heavier the line, because the engine can only completely utilise its power on so much less a portion of the line. But the cost referred to the ton-mile is so much greater, always for a same difference of level, because the load of the engine is so much the less, as the inclines are steeper.

The *right to the railroad*, independently of topographical conditions, has often been set up in principle under the pretence of distributive justice: France, unfortunately, has not escaped that fallacy. The right of a locality to be connected with the general network resulted there from the simple quality of head place of the *arrondissement* (*), that is to say from a fact which bears often no relation to the utility, at any rate immediate, of a railway. There is only the semblance of justice in this. Justice does not consist in endowing more favourably than others, districts placed in conditions natu-

(*) County town, in fact. (*tr.*)

rally unfavourable; not even in giving to each an equal portion in the distribution of the common funds of the country.

The State should, in general, invest, and not give in charity. The use of the common funds should profit the mass. If it only profits a group of local interests, the general interest is sacrificed thereto, and the distribution is not equitable. In delaying certain secondary lines, equally costly, and wanting in every feature of urgence, others, easier as well as more productive, might have had the benefit of resources which have been too much frittered away.

So to the great lines, notably those which fill up the gaps of the same system, or which join together the different sections of the Continental network, it was well to execute those at any cost. The crossings of the Alps: Mont-Cenis, the Brenner (I do not count the Semring, which would doubtless not be made in the present day), those of the Pyrenees (on condition of choosing them better), the Appenines, could not have been delayed longer, without compromising interests, every day more pressing.

The importance of the traffic permits, besides, in the most part of the cases of this kind, of all the works necessary to obtain a trace at least tolerable for locomotives.

367. *Limits of the inclines admissible for locomotive lines.* — It has often been asked what is the limit of inclination admissible on railways worked by locomotives. Although circumscribed and clearly defined in appearance, the question is still put in too general a manner to admit of a determinate figure in answer. There is without doubt an evident, absolute limit: it is that for which the engine, supposed with total adhesion, can just exactly draw itself, that is to say the inclination such that

$$\frac{P}{i}=fP\sqrt{1-\frac{1}{i^2}}, \qquad \text{whence} \qquad \frac{1}{i}=\frac{f}{\sqrt{1+f^2}}.$$

Below this limit, every inclination is rigorously possible; but at which to stop? Evidently, that depends.

The easier the ground, and the higher the probable traffic, the lower we go. Not only must the load drawn by the locomotive not be too small, but the establishment of the railway must not be unduly expensive. There must be compared, for different gradients, the loads drawn by a given engine, and the expenses of construction; and the limit of inclination must be determined to which corresponds, for a given traffic, the total minimum cost. But, as the limit of the gradients can only be lowered by increasing the

development of the curves, and often indeed reducing their radius, there must be brought into the account, the influence of these elements on the resistance, an influence imperfectly known, as we shall see (III, 313 and following), and which besides, involves the previous determination of the type of the rolling stock, engines and waggons.

368. *It is not the want of adhesion which in general fixes the limit of inclines.* — It is a very prevalent opinion, even among engineers, that the inclination admissible on railways is limited by the adhesion; so that we should be freed from this limit, and consequently from one of the great difficulties and of one of the heavy charges in the execution of railways in mountainous countries, if the adhesion ceased to be the obligatory intermedium of the effort of traction.

It is of consequence to discuss this opinion, which has no grounds but in extreme cases, and is quite wrong under ordinary circumstances, to which however it is applied. Even getting rid of adhesion as the means of transmitting the effort of traction, the result would be neither for the engines the possibility of any greater specific lightness, nor for lines with never so small a traffic, the faculty of admitting steeper gradients. Without doubt, this condition of adhesion fixes an absolute minimum of gradient, but this limit (367) is so high, as in practice to be unapproachable, by a long way; and that, because the useful effect of the locomotive diminishes very rapidly when the inclination increases, and becomes very small, even ridiculously so, far below this maximum of gradient determined by the adhesion.

This enormous influence of the gradients on the useful effect is self-evident. The locomotive is a dead weight. On the level, this weight only enters into the expenditure of work, by its passive resistances; but on an up incline, the work absorbed by the raising of the motor itself is a fraction of the total work, increasing very rapidly with the inclination; and there remains less and less for the useful work, that which corresponds to the raising and passive resistances of the train itself.

1. *Limit resulting from the smallness of the useful effect.* — T foot-pounds being the available work, in the unit of time upon the driving wheels (that is to say the work acquired by the pistons, diminished by that absorbed by the passive resistances of the mechanism), π the weight of the engine, P that of the train, V the uniform velocity, r the coefficient of resistance corresponding to that velocity, we have:

$$T = \frac{P+\pi}{i} V + (P+\pi)\sqrt{1-\frac{1}{i^2}}\, rV,$$

the first term being the work of gravity, and the second the work of the resistances. Reducing,

$$T=\frac{P+\pi}{i}V\left(1+r\sqrt{i^2-1}\right). \qquad (1)$$

$$\left.\begin{array}{ll}\text{For } \frac{1}{i}=0, & T=(P+\pi)rV \\ \text{For } \frac{1}{i}=1, & T=(P+\pi)V\end{array}\right\} \text{ which is evident.}$$

Neglecting 1 against i^2, (1) gives

$$\frac{P}{\pi}=\frac{T}{\left(r+\frac{1}{i}\right)V\pi}-1,$$

a relation which expresses the law according to which the ratio of the weight hauled to the weight of the motor decreases when the inclination increases.

The engine, then, only hauls a weight equal to its own when

$$\frac{1}{i}=\frac{T}{2V\pi}-r,$$

and it can only draw itself if

$$\frac{1}{i}=\frac{T}{V\pi}-r.$$

2. *Limit resulting from the want of adherence.* — The condition relative to the adhesion is :

$$f\pi\sqrt{1-\frac{1}{i^2}}>\frac{T}{V},$$

or again neglecting 1 against i^2 and at the limit,

$$f\pi=(P+\pi)\left(\frac{1}{i}+r\right). \qquad (2)$$

whence

$$\frac{P}{\pi}=\frac{f}{\left(r+\frac{1}{i}\right)}-1.$$

$$P=\pi \text{ for } \frac{1}{i}=\frac{f}{2}-r,$$

$$\text{and } P=0 \text{ for } \frac{1}{i}=f-r.$$

Example. Let the engine be one with a thousand square feet of heating surface, and weighing thirty tons; it can draw on a horizontal about 1.000 tons at 9,32 miles (*) (13 fet, 65 a second). Admitting for the coefficient of traction at their velocity 6 lbs, 62 per ton (or 0,003), we have

$$T=1.000\times 6{,}62\times 13{,}65=90.363 \text{ foot pounds.}$$

(*) The *Mediterranée* engines (1.268-1.308) with 1.090 sq. ft headting, weight 29 tns, 20, and would haul on the level, at 9,32 miles an hour: 1017 tons.

Bringing this into the expressions $\frac{1}{i} = \frac{T}{2V\pi} - r$, $\frac{1}{i} = \frac{T}{V\pi} - r$, it will be seen that the engine would only draw a weight equal to its own up a gradient of

$$\frac{1}{i} = \frac{90.363}{2 \times 13{,}65 \times 30 \times 2240} - 0{,}003 = 0{,}05, \text{ or 1 in 20,}$$

and that it could draw itself only up an incline of

$$\frac{1}{i} = \frac{90{,}363}{13{,}65 \times 30 \times 2240} - 0{,}03 = 0{,}103, \text{ or 1 in 9,7,}$$

Now the gradient-limits deduced from the condition (2) of the adhesion, would be respectively, admitting $f = 0{,}14$:

$$\text{for } P = \pi, \quad \frac{1}{i} = \frac{0{,}14}{2} - 0{,}03 = 0{,}067, \text{ or 1 in 15,}$$

$$\text{and for } P = 0, \quad \frac{1}{i} = 0{,}14 - 0{,}03 = 0{,}137, \text{ or 1 in 7,3.}$$

A velocity of 9,32 miles is to begin with, very low, so low that a railway of considerable traffic could hardly put up with it; on the other hand, an engine drawing only a weight equal to its own, the dead weight equal to the useful load, is certainly not a satisfactory position; a gradient which involves such a result is evidently out of reason and inadmissible; yet it is, however, as above shewn, very inferior to the limit resulting from the condition of adhesion : one in 20, instead of one in 15. It is not then, as is so often repeated, this condition which fixes the gradient limit in general, because below it there is a practical limit much lower, imposed by the consideration of the useful effect of the engine.

In fact, the point where the real practical insufficience of the adhesion commences, is relative, not to the inclination of the gradients, but to the velocity. If the adhesion fails on an incline sooner than elsewhere, this is not the consequence of the steepness of the gradient, but that of the low speed at which that gradient is, and ought to be run over.

The condition (2) relative to the adhesion, is independent of the velocity V. The condition (1) relative to the dynamic power, depends thereon. If V diminishes, the value of $\frac{1}{i}$ given by the relation (1) increases. This value may then become superior to that which results from the condition (2). Then does the adhesion fail, and a means must be of course sought for making up for it. But in the actual state of the construction of engines, this insufficience is only manifested at very reduced speeds, inferior to those required even for goods, in the working of lines of some importance. At 9 1/2 miles an hour, at 7 1/2 even (this figure depending on the climatic

conditions of each line), the adhesion is sufficient in general; and it is rare that the exigences of the traffic allow of a less speed, on account of the necessity of clearing the line, and often of duplicate ing the trains.

The real obstacle to the application of the locomotive on very heavy inclines is not then, the want of adhesion, but the smallness of the useful effect. The reduction of the gradients by lengthening out the line is a means largely used; but in that case the curves must be multiplied and their radii reduced; which is also a great drawback and a great difficulty. Particular care should be taken to avoid the occurrence together of the heaviest gradients and the sharpest curves, so as not to accumulate at the same point all the cause of increase of resistance.

This question of the relative measure in which inclines and curves should be admitted, is one of the most delicate in the determination of the trace to be applied to a heavy country, and the more so as the problem is not by a great deal, purely technical; the importance of the probable traffic rules every thing. The question, already examined in a general manner (263), of the choice to be made between one single engine and two engines of the same total power, presents itself again with quite a special character of importance, as regards traction on heavy inclines, requiring either the breaking up of the train, the application of auxiliary assistance, or both at once.

The auxiliary assistance may be applied in two shapes: either by the substitution of a more powerful engine for the running one, or by the addition of a second engine to the first. Whatever may be the conditions of the traffic, the organisation of the traction on very heavy and very long inclines should without hesitation, start with this principle: to work with double engines (unless for only light passenger trains which are always amply provided with brakesmen), and that so as always to have one engine behind.

369. *Engine behind.* The position of the auxiliary at the tail of the train is very much used now-a-days, but not yet enough however.

Some engineers have made out: that it was dangerous to push a train; that in case of accidents towards the head of the train, the consequences thereof might be greatly aggravated by the wrong action of the hind engine; that on a curve, pushing would cause running off the line; that the drivers so far apart would not be able mutually to understand each other, so as to act in common.

These remarks would be justified, if it were a question of making a general rule of coupling engines behind. They make complete abstraction of the conditions which justify it and demand it. This method has no right

at all excepting on heavy inclines; it conjures the great danger proper to these, that is to say breakage of couplings. Should it not, by chance, absolutely prevent these breakages, it prevents in general their too common effects, that is to say running down backwards, and the disastrous collisions thereby possible. At the same time that there is obtained a valuable guarantee of safety, that might be sought for in vain by other means, objections to the principle fall to the ground, trains on steep gradients running at very reduced speeds, and being generally very short.

The regulation of the 15th of November 1846, fixes besides at 15 miles an hour, the maximum velocity of a train pushed by an engine; the suppression of this limit had been requested by some companies; but the request was refused on grounds which do not go into the subject matter of the request: that a simple ministerial decision cannot affect a regulation having the force of a law.

In fact, the engine behind, thus applied, has never, so far as I know, been the cause of any accident: but it certainly has prevented a great number. It has been long in use on the *Méditerranée* lines, even on the relatively light gradients of *Blaisy* (one in 125); and it is now fourteen years since it was made compulsory by Government on the incline of the *Givet* line, to the Belgian frontier. This incline, which runs down towards *Givet*, having in several instances procured that station the sudden and most objectionable visit of mineral-waggons having broken away from ascending trains, the department ordered that, when the weight of the train required an auxiliary Control engine, that engine should be put on behind.

Independently of the question of safety, it is a matter of no small indifference to save the couplings and the frames, which suffer severely on heavy gradients, when there are two or three engines at the head of a train.

Since 1869, all the goods-trains, until then divided in two, and taken up in separate halves on the Semring, are taken up in one, by two engines, one at the head, the other at the tail. M. *Gottschalk*, locomotive engineer, shews that, contrary to the opinion of his predecessor, M. *Desgranges*, pushing gives rise to no objection, in spite of the curves and return curves of 623 feet radius. Definitively adopted at the Semring, the engine behind is so with greater reason at the Brenner, where the curves are much less sharp. For the crossing of the Appenines at *Giovi*, it has been in use from the beginning.

On inclines of one in 50 to one in 33, and even below, there are scarcely ever enough brakes and guards to goods-trains to prevent running backwards, when a coupling gives way, positively and at whatever point the failure occurs. The engine behind, is the only radical means, or nearly so,

for it also may turn out insufficient, if the coupling breaks near the head of the train.

Examples. I shall first cite as example, a series of accidents, not very serious, by the way, occurring toa train which presented the three circumstances of undue size, double engine at the head, besides an engine behind, with careless or bungling driving.

Goods-train 2472, from *Lyons* to *Nevers*, on the 31st May 1870; fifty-six waggons (348 tons); two engines with six wheels coupled in front; a sixwheeled engine behind. Between *Tarare* and the *Sauvage* tunnel, first separation of the train on account of the breakage of the hind cross transom of the eighth waggon. The forty-eight others, which the engine behind and the brakes were at first incapable of mastering on the gradient of one in 38,5, were stopped after a run backwards of 430 yards. The front part shunted the coupling was replaced and strengthened. The train started again; but after only 645 yards, fresh breakage of the same coupling. Fresh repair, fresh starting; and 423 yards farther, fresh breakage, which was again made good. For greater security, the train, which might have given up its hind engine at the top of the great incline, kept that engine until it had passed through the great tunnel, and ran down with its two engines in front to *Amplepuis*, where it was pulled up at the signal. In starting after that stoppage, a new and last incident: separation of the train at the fifth waggon from the end.

The drivers certainly managed this unfortunate train very badly; they showed a want of precaution and proper understanding with each other; but also, the effort exerted by the two engines at the head was excessive for the couplings, and above all for the guard-chains on passing through curves. The first breakage, that of the transom, took place, in effect, just at the point where the outside chain was fixed.

The consequence to be drawn from this journey of accidents, and of some other facts of the same nature is, that the composition of the trains on the line in question ought not to exceed that which corresponds to the power of two engines; and that if by exception a third is necessary, on account of the load, or of the state of the rails, such third engine should be put, not in front but behind; that, in a word, double *pushing* is preferable, on heavy gradients, to double *traction*.

We have only complained of the too great mass of the train, and not of its length; as, in effect, the great length is not a serious objection, provided the curves are not too sharp. The pretended rupture of the train by giving way in the middle under the action of pushing behind is not to be feared;

on the *Méditerranée*, an axle of the leading engine of a train of fifty seven waggons, pushed behind, broke without involving any accident; the front driver was able to slacken on his own account and signal the driver of the hind engine to do the same. The whistle is in fact the ordinary means of corresponding between two drivers, as well when their engines are following each other, as when they are some hundreds of yards apart; and it is pretty much as efficient in the second case as in the first.

The engine behind is not always even sufficient, as we were saying just now, to avert the consequences of the breakage of a coupling; the *Méditerranée* has had experience of this on several occasions. In such matters, examples are always instructive:

The 16th of March 1871, a train of fifty three empty waggons drawn by two engines (sixwheeled), one in front and one behind from *Mouchard* to *Pontarlier*, was pulled up at the 259,4 mile by a considerable mass of snow. The reaction produced by this sudden stoppage caused the breakage of the couplings between the fourth and fifth waggons. The hind engine (No 1101) would not have been able to keep back the other forty-nine waggons, thus separated from the head of the train, on the gradient of one in 50. Intentionally or not, but in any case rather a rough proceeding, the driver brought in a new resistance: opening abruptly his regulator he gave an impulse to the engine, which caused the five waggons immediately in front of him to go off the line; the first two next to the engine went off down an embankment of 32 feet and were smashed; the three others, only leaving the rails, but not the formation-level, thus formed a powerful brake.

At the same period (night of the 14th to 15th of March) they were within a hair's-breadth of a catastrophe on the extension of the same line, worked by the Swiss Company; a train of thirty two carriages was bringing back French soldiers. In starting at *Boveresse*, a coupling broke towards the head of the train; the train ran back with a frightful speed, but fortunately without meeting with any obstruction, as far as *Travers*, where they managed to stop it. But in this case, there was no engine behind.

Nearly at the same period, again on the direct line from *Nîmes* to *Paris*, a train was mounting the *Villefort* incline (one in 40), having in front and behind, an engine with eight wheels coupled. The tender-coupling of the front engine gave way; the train had by a lucky chance, or which should have been such, a number of brakes superior to the regulation number, five instead of three. The means of stoppage being in excess, the running backwards of the train ought to have been immediately got under. It was not so however; the train ran into the *Villefort* station with a considerable

velocity, and smashed waggons which were standing there, itself running off the line. The driver of the hind engine, which thus became the front, was killed.

It is impossible, evidently, to see in these accidents any argument against the utility of the engine behind; it may by times prove insufficient, that is all; and still if, in the actual case it failed in efficacity, it is that the men were wanting in presence of mind, or to be more just, rather in the necessary freedom of action. The breakage of a coupling has taken place in a tunnel the passage through which is, and above all was very severe on the ascent, from the want of ventilation; the men did not probably notice the train was running backwards until the velocity had already become considerable, and the working of the brakes too late. It was even supposed that the driver of the hind engine might have in his trouble moved the reversing lever without bearing in mind that the counter-steam was acting by the very fact of running backwards. If this supposition is at all likely, it is only because a fact difficult to explain otherwise is accounted for thereby; for, on the other hand, the very position of the lever ought to have prevented the driver, even without thinking, from the error attributed to him.

370. *Tunnels badly ventilated. Increase of this drawback by engines behind trains.* — By its circumstances, this accident is connected with the only objection of any gravity raised against the engine behind. In the tunnels of a certain length, and on steep gradients, the position of the hind driver especially is distressing. He is suffocated, particularly if the engines slip, which is frequent, by a cloud of steam mixed with the gases from the combustion, and the evil is naturally serious especially in tunnels of small cross section for only one line. Too much trouble can hardly be taken to insure a smart draught in these tunnels; unfortunately, the action of the shafts is far from being sufficient at all times.

The 27th October 1871, the goods-train No. 1.604, drawn by one engine with eight wheels coupled and pushed by another, parted in the *Altiér* tunnel near *Villefort*, by reason of the falling out of the key which fastened the drawn bar into the buckle of the spring. The guard-chains that time held on, but by tearing off the cross-beam. The hind engine and the brakes kept the train in the tunnel, but the driver was nearly suffocated. The men of the train did not dare to let it go very slowly backwards, until the engine was out of the tunnel; which would have been excusable, but irregular.

Insufficient for purposes of ventilation, the shafts would besides be often completely obstructed, unless some steps were taken to prevent it. In the

tunnel of *le Sauvage* (369) for example, numerous icicles form during the winter in the shafts, which in a thaw fall to the bottom. In rigorous winters, the thickness of the ice reaches to about 50 feet. Under this pressure, the lower layers of this sort of glacier slid along in the heading and got to the tunnel itself on to the permanent way. Walls ten feet high built across the headings to stop this movement, were surmounted; they were raised to thirteen feet, and the rest of the section fitted with an open wooden frame work, to keep as much as possible the circulation of the air, when the shafts are free. A similar arrangement had already been carried out several years before, in the *Blaisy* tunnel.

In tunnels of large cross section, even the longest, as those of *Blaisy* 2,55 miles, of *la Nerthe* 2,96 miles, the want of ventilation is not seriously felt. They have not however, as those of the *Villefort* line, heavy gradients which involve slow running and slipping in going up.

371. *The great Mount Cenis tunnel.* — Far from being an obstruction, a steep incline is sometimes, on the contrary, the principal cause of a powerful draught. Such is the case in the great tunnel, with large cross section, of *Mount Cenis*, which presents from the northern entrance (*Modane*) as far as the middle, that is to say for 3,89 miles, a rising gradient of one in 44,4; and from the middle to the southern entrance (*Bardonnecchia*), a simple incline to carry off the water, one in 2.000. There is thus between the two entrances a difference of level of 443 feet, and the interior air being heated by contact with the rock, the temperature of which reaches at the middle about 80° (F), a regular draught sets up in that immense chimney. The direction of the wind modifies this action; the north wind is favourable to it, the south wind on the contrary is against it. This is the same as regards the direction in which the trains are running, the action due to which on the composition of the atmosphere of the tunnel is besides very different according to that direction, the trains from *Bardonnechia* to *Modane* sending incomparably much less steam and gas into the tunnel, than the trains mounting the other side. If the ruling state of things is a current from south to north, stagnation, unstable equilibrium besides, and the reverse current, equally occur. But in fact, the fears expressed as to the want of ventilation had no grounds, at least as far as regards the actual traffic, which every thing shews may be considerable without any difficulties arising from this source.

In any case the worst would be, to apply to the working of the line, the same ventilation found to be indispensable during the excavation of the

tunnel, and which perfectly sufficed, in spite of the great number of workmen, lamps and blasts.

M. *Amilhau*, engineer, director general of the railways of Upper-Italy has given tome the following note on this important question :

Turin, 19 mai 1872.

. . . .

" The ventilation of Mount Cenis, as far as regards trains, is something marvellous. I appeal, for the confirmation of this, to the testimony of the passengers who have passed through it, and especially of a party of traffic-managers from the French railways who went through yesterday with two engines, after the passage of three trains, and under the worst atmospheric conditions, with heavy and rainy weather, without wind.

" As to the platelayers and inspectors, they suffer sometimes from the smoke in which they are momentarily enveloped, but the same inconvenience occurs with greater force in the *Giovi* tunnel, which you know well, and where I shall be obliged to distribute air-boxes so that the watchmen and road workmen need not remain permanently under the shafts.

" At the Mount Cenis tunnel we keep in reserve the conduit of compressed air which I have had placed the whole length, with openings every 275 yards; but up to the present, it has not been necessary to make use thereof.

" It seems to me that the underground railway of *Paris* could be ventilated by the aid of shafts like the openings into the sewers. In every case, it is ascertained that the width of the tunnel plays a principal part in the supply of air to the trains. The tunnels on the *Pistoja*, even those of *Exiles* and *Meana*, on the Mount Cenis line, which are only constructed for a single line, are suffocating for the passengers; while in the great tunnel, the smoke beats along the arch and goes off by the line on which the train is not running. I should also mention to you that the use of coke caused serious cases of suffocation to the drivers and brakesmen, on the *Pistoja* line, while the coal smoke although much more uncomfortable and disagreeable, has produced nothing of the sort. I have thus been obliged to prohibit absolutely the use of coke. "

Several months afterwards (6th of October) a certain sensation was produced by an incident: it was reported that a passenger train had broken down in the great tunnel, on account of the suffocation of the driver and fireman, and the Upper-Italy company published the following note on the subject, fully confirming part of the report, but putting the facts right:

. . . .

" The result of the inquiry made into the occurrence which took place in the Mount Cenis tunnel on the 6th instant, is that the ordinary passenger-train from *Modane*, which had to be signalled to stop on account of a goods train standing broken down on the line, was exposed to no danger. The passengers had to suffer from the smoke of five locomotives, which happened accidentally to be all at the same time within the tunnel; but none of them felt so far indisposed as to call for any remedies, or particular

attention. The drivers who had the most to suffer from the smoke, returned to their work the next day.

"A concourse of unforeseen circumstances, which the experience acquired by the occurrence will prevent for the future, was the sole cause of an incident which ought in no way to shake the confidence of the public in the conditions of safety presented by the passage through the tunnel."

There was, in fact, a slight collision between the passenger train and the goods-train which preceded it; the pulling up of these trains, the accumulation of several engines in steam, the impossibility of the drivers, guards and so on seeing and hearing, and more especially of breathing, might have produced serious results to an accident, which would have been nothing in the open air. After several ineffectual efforts to continue the journey, with an engine behind, it was decided to take the train back to *Modane*, and to let the atmosphere in the tunnel clear.

This example was not required to show that in great tunnels more particularly the one in question, every possibility of a collision must be avoided; and no alarm should be taken at an occurrence, which it is easy to prevent a repetition of.

If cases of suffocation have taken place in the *Giovi* tunnel in spite of its large section and relatively small extent, it has been that these favourable circumstances were compensated far by the great activity of the traffic, and the frequent slipping. As to the tunnels on the line from *Bologna* to *Pistoja*, they are of still smaller extent, but curved and of small section.

372. *Trial of Galibert's apparatus.* — Passengers have not so very much to suffer, in general, from the imperfect ventilation of tunnels. The engines which draw their trains, less heavy, are less liable to slipping and so to lengthening their time in the tunnel. They have only to raise the windows to procure a supportable atmosphere for themselves for a certain time, especially if the compartments are not full.

It is not however the same with the employés of the trains, of goods trains especially, and amongst them particularly those at hind part of the train: guard, driver and fireman of the hind engine.

On the *Méditerranée* system, as on that of Upper-Italy, it was thought to utilise for the sake of these men, an apparatus which has been attended with success, in allowing persons to enter noxious media, that of M. *Galibert*.

A service order of the locomotive and traffic departments dated the 31st of January 1872, gives the description and regulates the use of that apparatus.

We reproduce that order. But truly speaking, too much reliance should not be placed on the carrying out of these measures, which are more simple in appearance than in reality.

Some weeks after the apparatus was put on the engines, the guard at the end of the train No. 1.604, leaving the *Albespeyre* tunnel, on a rising gradient, saw neither driver nor fireman on the hind engine, which immediately followed his van. He managed to get on to the engine, where he found the two men stretched out insensible on the foot-plate; he whistled for the brakes, and shut the regulator, which by the way broke a coupling. The two suffocated individuals soon regained their consciousness. Questioned as to their negligence as to the use of the preservative means at their hand, they replied that "no one could work with that". This is without doubt only a matter of education; but is difficult, so great is the indifference on the part of workpeople as regards personal precautions. They fear more what is irksome, than what is dangerous. However, since the shafts have been cleared out, the air is much better in the *Albespeyre* tunnel, and serious accidents do not seem to have occurred since.

Use of respiratory apparatus in the tunnels on the line
from LA LEVADE *to* LA BASTIDE.

" The drivers who take goods trains on the section from *Alais* to *La Bastide*, with engines with eight wheels coupled, sometimes suffer discomfort in passing through the tunnels, especially in that of *Albespeyre*.

" These discomforts are due to the small section of the tunnels with respect to the production of the deleterious gases, which vitiate the air, and act immediately on the employés of the trains before the air has had time to be replaced.

" We have provided all our eightwheeled engines, in service on that section, with air apparatuses, provisionally, which allow the employés to breath without danger in noxious media.

" Experiment has given excellent results, and we are constructing at this moment permanent apparatuses which will be applied to all these engines. The description and the rules to be followed, for the use of these permanent apparatuses, are indicated in the following articles:

" The permanent apparatus includes:

" 1. A short iron base fixed on the hood of the engine and serving to store the air fit for breathing;

" 2. An india rubber tube, conveying the pure air from the case to the lungs;

" 3. A mouth piece;

" 4. A nose-clip;

" 5. A system of tube work intended to renew the air in the case.

" The air case is divided by a vertical partition into two equal compartments, placed symmetrically with the longitudinal axis of the engine. Each compartment, isolated

from its neighbour, has a capacity of 8,5 cubic feet, and constitutes a reservoir, in which pure air is stored at the atmospheric pressure.

" When the apparatus is used to breathe with, the air from the case breathed by the lungs, is returned afterwards into the same case.

" Thus an air less and less pure is breathed, the more the respiration is prolonged; but the air becomes only gradually vitiated, and the respiration may be thus continued for at least forty minutes without fatigue being felt.

" The driver and the fireman can both breathe at the same time, but separately, and without the products of their respiration mixing, by passing from one tube to the other.

" A flexible pocket in india-rubber is fixed on the inside, at the bottom of each reservoir, and communicates with the external atmosphere. This pocket, during the breathing, alternately dilates and contracts, and maintains the air of the reservoir at the pressure of the atmosphere, which allows the lungs to act freely and without effort.

" A cock placed externally at the lower part of each reservoir finishes by a connection to which is adopted an india-rubber tube, which conveys the air from the case into the lungs. This tube is 0 in, 39 in diameter, and about 5 feet long.

" The mouth piece is in hardened india-rubber; its form and dimensions are those of the human mouth; it carries, on the side opposite to that in contact with the lips, an appendix which serves to fasten it to the india-rubber tube.

" The nose-clip is in wood; it has the form of a small pair of pincers and holds firm by means of a spring. It is intended to prevent the introduction of air through the nostrils.

" A pipe for each reservoir takes the air vitiated by respiration; these two pipes unite in one common discharge pipe.

" The junction is provided with two cocks, which serve to establish or to intercept the communication between the discharge tube and the tubes which pass into the reservoirs.

" An opening at the lower part of each reservoir, in the corner by the pillar supporting the hood, serves to introduce pure air into the case, in place of the vitiated air.

" A valve worked by hand, allows this orifice to be opened or shut.

" The renewal of the air in the case is produced by a steam blower.

" This blower is composed of a tube, one end of which is fixed to the front of the fire-box, and the other end of which terminates in the upper portion of the discharge tube.

" Under the action of the blower, a current is set up from the entrance opening to the discharge tube, passing through the reservoirs; the vitiated gases are carried off with the steam into the discharge tube, and replaced by the external air.

" The reservoirs being filled with pure air, all the communications between the interior of each reservoir and the surrounding atmosphere should be kept closed, in order to prevent the loss of pure air, and the introduction of the deleterious gases.

" When it is desired to make use of the respiratory apparatus, the following steps should be taken:

" 1. To fix the mouth piece between the teeth with a slight pressure and apply the lips round the outside of this piece, so as to prevent the introduction of the external gases into the mouth;

" 2. To put the nose-clip on the lower part of the nose;

" 3. To open the cock which establishes the communication between the india-rubber tube and the reservoir of air;

"4. To breathe without effort, in the ordinary manner.

"When it is desired to leave off the use of the apparatus, for any length of time, the following should be attended to:

"To close the communication between the india-rubber tube and the reservoir;

"To withdraw the mouth-piece from the mouth;

"To take off the nose clip.

"To renew the air of the reservoirs, the following must be done:

"1. Open completely:

"The entrance valves;

"The communication between the reservoirs and the discharge tube;

"The steam jet cock.

"2. Leave things in this state for at least one minute.

"3. Close successively, and in the order stated below:

"The steam-jet cock;

"The communication between the reservoirs and the discharge tube;

"The entrance valves.

"These operations concluded, the driver and the fireman can, whenever circumstances require, take fresh respirable air from the apparatus, according to the rules laid down above.

"The renewal of the air ought to take place:

"1. A little before starting, and outside the sheds or engine dépôts;

"2. On leaving every tunnel.

"The fire-box door should remain closed during the renewal of the air in the case.

"All the men on the engines drawing goods-trains with eight wheels coupled, from *La Levade* to *La Bastide*, should make regular use of the respiratory apparatus during the passage through tunnels which present danger, on account of the affluence of the deleterious gases, and particularly in the *Albespeyre* tunnel.

"To that effect, from this day the provisional apparatuses will be employed, and later on, these will be replaced by the permanent apparatuses, when fixed.

"In the latter case any other men besides the driver and fireman who happen to be on an engine, shall continue to make use of the provisional apparatuses.

"These men will be responsible for any accidents which may happen to themselves, or to others, through inattention to the preceding rules."

It can readily be understood that the companies should commence trying expedients of this sort, which would free their responsibility in cases of accident; but they are of doubtful efficacy, and are also insufficient. Although less exposed than the men on goods trains, passengers are not quite disinterested in the question; a passenger train, above all a goods train containing passengers, may come to grief in tunnels on a rising gradient; and what there should be for the passengers is a respirable medium, and not the *sauve-qui-peut* of *Galibert's* apparatus; of which, besides, there would not be enough for everybody. In the tunnels with insufficient natural draught, an artificial draught as in mines is necessary; and, in certain cases,

as in the underground *London* Metropolitan, where the traffic is enormous, special arrangements are also necessary to stop the discharge of the gases from the fire-box, and of the exhaust steam. We shall examine these arrangements late on (III, 136 and following).

But on the great lines, the simplest and surest precaution, that which should always be attended to, is to avoid stoppages and slipping in tunnels; and what too often causes these, is the overload of the engines.

373. *Tunnels with too much draught.* — There often is in tunnels of ordinary dimensions too great an amount of ventilation, which is striven to be reduced in winter, because it then is attended with indirect inconveniences; if the drips are somewhat plentiful, their freezing, under the influence of an active current of air produces the formation of stalactites which end by falling off, and sometimes injuring the drivers, when incompletely sheltered. It is on this account that at the *Hauenstein*, at the *Semring* tunnels and others, the entrance exposed to the winds is provided with curtains or doors, habitually closed in winter, and which the attendant opens when a train is expected.

374. *Insufficient ventilation of the snow-shelters.* — If natural ventilation is at times too active, it often fails in other cases that tunnels, and in circumstances where it would be at first supposed sufficient. To protect the temporary line over Mount Cenis from the snow, it was necessary to cover it over, for a great portion of its length by galleries in timber and sheet iron. In spite of numerous openings in the sides, and in spite of a wide continuous slit left, with no small inconvenience, the whole length of the ridge, the passage of these galleries was, on the ascent, very trying to the men. The steam and the smoke mixed slowly with the air, almost stagnant in spite of the numerous communications with the outside, and by which also the snow got in.

The long wooden galleries constructed on the Pacific railway, in the high regions of the Rocky Mountains and the *Sierra Nevada*, are completely separated from distance to distance, at the least threatened points, and the vertical sides supporting the roof with two gutters, are, as often as possible, open-work.

375. Let us return to the engine behind. Beyond safety, it has another advantage, a secondary one it is true: steep gradients are run over, on account of the low speed, very close to the limit of adhesion; when the rails

are wet, the hind-engine finds them cleaned and dried by the passage of the whole train, and profits thus by a higher coefficient.

Besides, the opposition of many engineers, who were at first against a measure, altogether so useful and so salutary, has ended by yielding to the evidence.

It is almost unnecessary to say that the auxiliary engine when it is retained for the descent on the other side, is brought, at the summit, to the head of the train.

376. *Disadvantage of sudden changes of gradient.* — Lines with great changes in the section are at times subject to difficulties of working, and even to dangers, which a little more care in the construction would have been able to avoid or to modify: those which result from too abrupt changes of gradient. Ascending, it is especially at passing without transition from a steep gradient on to a flat one, or on to a horizontal, that the concentration of a considerable motive power at the head of the train tends to induce the breakage of couplings. The engines coming on to the horizontal, tend to increase their speed, and exert a very considerable increase of power on the train still on the incline, which may separate the train, and let part of it run backwards.

Descending, the effects are naturally less serious; and it is no longer a case of running backwards. But two portions of train following each other on a steep gradient, are very much exposed to a collision.

Open for traffic at the end of 1871, the section from *Saint-Jean-de-Maurienne* to *Modane*, has been almost from the commencement, fertile in incidents arising from the section. The 17th of April 1872, a goods-train (1.304) of 27 waggons (261 tons of useful load) and 5 locomotives in front was descending from *Modane*. At a point where the incline passes abruptly from one in 200 to one in 38 1/2, the coupling gave way behind the fourteenth waggon, under the impulse of the five engines which had entered on to the latter gradient. The first portion went on, but without any acceleration, as there ought to have been. The second portion composed of 13 waggons with only two brakes, could not be controlled, and came up to the first portion, with a violent shock, at the end of a space of 440 yards. The number of engines was excessive. It is very difficult for five drivers to combine their operations, that is to say, in this case, the application within suitable limits of the means of stopping, as soon as they reach the point of the change on to the steep gradient, in order to subdue the effort of traction. Already, on the 12th February and 28th March of the same year, breakages had

occurred in the same train, between *Saint-Michel* and *Saint-Jean*, at a point where the gradient passes abruptly from one in 200 to one in 43 1/2.

The train 1.305 of the 22nd June 1872, as it left *Saint-Michel*, consisted of:

1 engine (1.902) sixwheeled;
43 loaded waggons;
4 empty waggons;
6 empty carriages;
3 loaded waggons;
1 engine (2.315) eightwheeled.

At the 115th mile, where the gradient changes abruptly from one in 125 to one in 62 1/2, the coupling behind the front engine gave way, by the fracture of the screw-shackle clip; the guard-chains gave way also; they never do otherwise. The train went back on the hind engine, which gave way at first for a distance of twenty yards, then held on. Pressed in between the loaded waggons, and the hind-engine, the empty waggons and carriages, the buffers of which were higher than those which were pressing against them, lifted up and went off the line, smashing in panels, etc.

At the commencement of the same month, running backwards happened very frequently. On the 8th, it was the train 1.301 A, which had its front coupling broken in front of the van, caused by slipping, towards the summit of the tunnel of *Sorderettes*, on an incline of one in 33. For 42 waggons (279 tons useful), there were only two brakesmen: the conductor in front, the guard behind. The whole train went down backwards, the counter steam of the hind-engine, and the two brakes being quite insufficient, and it was not stopped until after a mile and a quarter, at the *Saint-Michel* disc.

The next day, it was the turn of the extra train 2.303 of 150 tons, with a single engine (8 wheels) in front. At the same point of the tunnel the coupling broke between the 12th and 13th waggons, and the tail of the train of seven waggons with two guards passed, in spite of the brakes screwed down home, through the station of *Saint-Michel*, and was only stopped a mile and-a-half beyond, thanks to a plate-layer who managed to place some obstacles on the line. Three days afterwards, the 12th, it was the 1.301 A again with 27 waggons (271 tons) with engines both behind and in front, which had, always in the *Sorderettes* tunnel, a coupling broken between the 4th and 5th waggons. There were only two brakes, and only one in the 23 waggons which went down backwards, and were only stopped, in spite of the counter-steam, after running upwards of a mile. There was nothing to be found fault with here, but the insufficience of the means of stopping: They were risky proceedings. But it is not here the time to discuss that point.

377. *Question of the coupling on or of the simple juxtaposition of the engine behind.* — There remains for us to examine, on the subject of the engine behind, a question of a certain importance; ought that engine to be attached to the train or not?

Not attached, it can leave without stopping the train; but at the same time the engine and the carriages may by reason of some wrong operation separate from each other, and then come together again violently.

There is, in fact, in this position, an abrogation of the rule as to the space between successive trains, for whether drawing vehicles or not, an engine is really and duly a *train*, in the regulation sense of the word; but an engine solus is so manageable, that there must be great clumsiness on the part of the driver to cause a collision in this manner, however trivial. Simple juxtaposition has been, at any rate, practised for a long time on many lines without any accident, and it would be somewhat too much to absolutely prohibit, by acting up to the very letter of the law, a simplification which has its value. Every thing depends on the section of the line. If it be nearly uniform, coupling seems useless. If it is very varied, and irregular, the driver of the front engine may be perhaps, induced at certain moments, to increase rapidly the speed of the train; the driver of the hind-engine can scarcely in that case avoid separating from the train, and it is always difficult and ticklish to join on again during running.

Example. The goods trains from *Marseilles* to *Pertuis* take on the auxiliary behind, at *Les Milles*, to surmount the incline of one in 66,6 which ends at *Aix*. The 18th of January 1872, the driver of the train 2.377 increased his speed before getting to the foot of the incline; the back engine, left a little behind, in rejoining the train, seriously damaged the hind brake-van. In this case coupling would have been better, all the more as the consideration of letting off the engine without stopping the train does not come in, the engine following the train as far as *Aix*, where it stops.

The question has not been studied as it should have been, and on the different points of the same system, one of these two ways is found to prevail, without the choice being always explained by the difference of local conditions

Thus, it never has been for a moment thought of to suppress coupling on the *Blaisy* inclines (near *Dijon*), neither on the line from *Pontarlier* to *Mouchard*. A service order prohibits it between *Roanne* and *le Coteau*, between *Balbigny* and *Vendranges*, and rightly enough, on account of an incline which breaks up these two sections; and at the same time, there is no coupling, not only on the two sides of the summit of *le Sauvage*, between *Seysel* and *Bellegarde* (*Ambérieu* and *Geneva* line), between *Rive-de-Gier* and

Saint-Étienne, on the Dauphiny lines, etc., but also on the lines from *Aiguebelle* to *Modane*, and from *La Levade* to *La Bastide*.

The want of connection may prevent breakages of couplings. The abrupt stoppage of the engine behind, has in effect produced these breakages, but the connection involves, on variable sections, accidents much more frequent and more serious. The two drivers can with difficulty run in accord on such sections, and avoid parting and buffers striking, of which the breakage of a coupling is the most frequent, and at times the least serious consequence. In as much as these partings and striking of buffers are too difficult to avoid, simple prudence leads to opposing thereto the connection of the engine with the train, even should some broken couplings be the result, which the engine being separate in no way prevents however, while it may involve more serious accidents.

Simple juxtaposition may be admitted, however, when the approximate uniformity of the section becomes changed for a certain continuous length. Thus on the portion of the direct line between *Nîmes* and *Paris*, from *la Levade* to *la Bastide*, the up gradient ceases abruptly from mile 403 to mile 388,5, and gives place to inclines down, of one in 1.000, one in 500, one in 333; when the beginning of these gradients is reached, the train rapidly increases its speed, the auxiliary engine reduces its speed, and follows the train at a respectful distance as far as the station of *Chamborigaud*, where it stops; the engine comes on then and takes its places again behind.

But on the same line, between *Coucoules* and *Villefort*, the section presents at first rising gradients varying from one in 175 to one in 52,5, then falling from one in 143 to one in 200. It is very difficult for the driver of the hind-engine to keep properly in contact with the train on such a section; so the men much prefer the old practice of coupling.

378. *Steep gradient engines do not differ from slow speed engines on flat gradients.* — Locomotives devoted to working inclines, differ in nothing, up to a certain very high limit of gradient, from those which run on flat lines, but at a low speed. Having like the latter, to exert at a low speed a large tractive power, they also require small wheels, and the adhesion of the whole weight. An engine which works at nine to twelve miles an hour on a level, with a heavy load, utilises its power quite as well at the same speed, on an incline of one in 33 and one in 25. All the difference is that the same effort of traction which overcomes, in the first case the passive resistances of the engine and of *a great number of waggons*, overcomes particularly, in the second case, the component of the weight of the engine

parallel to the incline, and of *a less number of waggons*. A steep gradient engine is nothing else, then, than a slow speed engine. These may be quite elementary truths, but they are not always fully appreciated; thus we must not hesitate to insist on them.

There is however a shade of difference to point out. On a level, the engine is only a small fraction of the load which it draws at a low speed, so that in view of the useful effect, there is no great interest in some little reduction of its weight. It is not the same thing on a steep gradient; the weight of the engine is then a very considerable fraction of the total weight drawn, and even a slight reduction becomes of great importance. Specific lightness must therefore be the more aimed at, the steeper the gradients are on which the engine has to work.

Thus we see the error of those (and their name is legion) who make out that engines are made specifically heavier, the steeper are the gradients they are intended for. It is the contrary which is true; and if the speed run at were low enough for the adhesion to fail, recourse would be rather had to the expedients pointed out farther back, than to an over-load.

379. *Low speed of all trains on the ascent and on the descent of steep inclines.* — It is clear that on a heavy gradient, one in 33 per example, and even below, there can be no question of high speed, for passengers any more than for goods. Both the one and the other run very often at one and the same speed, very low.

On such gradients, the resistance due to gravity is much greater than the sum of the others. Even for a very light train, the effort of traction necessary surpasses that which can be developed by an engine with an ordinary amount of heating surface, and consequently of ordinary power, running at a high speed. It is essential then to run at very reduced speed, in order that the inversely proportional increase of the effort of traction may allow a less insignificant load to be taken. Thus is accepted, even for quick trains on the rest of the distance, a very marked reduction of speed on steep gradients; and as these are fortunately exceptions, the mean velocity is not in general seriously affected. Hence it follows that engines for high or mean speeds, characterised by large or average sized driving wheels, and by partial adhesion, disappear completely on steep inclines, which are worked entirely by engines with small wheels all coupled.

The loss of time in ascending gradients is not compensated by an acceleration of speed in running down. Far from being greater than the velocity on a level, the velocity down an incline is not equal to it. Ordinary pru-

dence requires that this should be so. The driver ought always to have his train in hand, or, to speak more precisely, to be in a position to obey the signals made at the regulation distance from the points to be protected, a distance which cannot go beyond a certain limit, a mile and a quarter at the most. It is thus necessary that the speed at which a driver is running when he is surprised by a signal to stop, should be so much the less, the greater the accelerating force independent of him, which acts on his train. The relatively small mass of the trains which run on steep gradients, fortunately reduces the *vis viva* therein accumulated, and the means of stoppage can and ought to be proportionally greater thereon. But the condition of low speed is none the less absolutely necessary.

On lines with ordinary gradients, heavy goods are carried slower than ordinary passenger trains, and these again slower than express trains, only containing first class. Thus the useful load is carried at the velocity which its mean tariff will pay for; and this tariff ought to be so much the higher, as the mass diminishes when the velocity increases.

It seems that the same scale of speeds ought to be in force on steep gradients. But its differences are then much less : to avoid taking an insignificant load or employing engines of excessive power, the velocity of quick trains should be reduced almost to the same as that of goods-trains.

The latter may be reduced in its turn; but this reduction, limited by the condition that the effort of traction should not reach the amount of the adhesion, is still more limited on the great lines by the exigences of the traffic. To satisfy these exigences, the trains must not take up the line too long, and the more so, that unless by the employment of special engines of great power, and having recourse regularly to two or more engines, the trains are often broken up, and consequently more numerous on inclines than on the rest of the distance. It is thus for example, that on the incline of one in 36 on the mean, which makes up the difference of level of 951 feet, between *Pontedecimo* and *Busalla* (line from *Genoa* to *Turin*), the speed of the goods trains is fixed at 12 miles, that is to say little below that of goods trains on lines of average section, and higher even than that adopted by several with better gradients, but less traffic. It is a question of traffic; according as that is more or less considerable, the reduction of speed is more or less largely applied. Thus, the goods trains run at only nine miles on the line from *Mouchard* to *Pontarlier*, where the gradients do not however exceed one in 50, as on the portion between *la Levade* and *la Bastide*, one in 40, as on the inclines of one in 33 between *Saint-Michel* and the great tunnel of Mount Cenis.

As to passenger trains, the service on this last section seems to be in op-

position to the principles laid down just now, of the very approximate equality of the speeds of the same trains up and down the steep inclines, and slight differences of speed for the divers categories of trains. The timetable shows in effect for the up express (train 261) 16,75 miles, and down (train 274) 24,8 miles; while the goods go up and down at 9 miles. A mean speed of 25 miles an hour on inclines of one in 33 would be evidently excessive, and imprudent. It exists fortunately only on paper. In fact, the controlling engineers have ascertained that the express and the Indian mail go up and down at 16,75 miles; and the ordinary passenger-trains as well as the goods, at 9 miles.

380. Let us sum up in a few words what precedes:

The vice of the locomotive, on heavy inclines, is the smallness of its useful effect, on account of the excessive influence of its own weight, this weight being entirely the result of its power.

As to the complaint of want of adherence, for that to be well founded, one of these two things would have to be the case:

1. Either the adhesion of an engine should become reduced by the simple fact of its position on an incline;

2. Or having always the same adhesion as on a level, it should require, on an incline, a greater amount of adhesion in order to utilise its power.

Now as to the first point, there is certainly on an incline a reduction of adhesion; but how much? On an incline out of all bounds, even impossible, one in 10, the adhesion is 99 per cent of what it is on a level, and below that when we come within possible limits, the deficiency is infinitely small (275).

As to the second point, it is amply proved that, at *equal speed* the engine requires neither more nor less adhesion on an incline than on a level. Developing the same available work, it exerts the same effort of traction, and that being so, requires the same adhesion as on a level, neither more nor less.

The complaint which we are discussing, and which is constantly laid down in absolute terms, without the velocity being in any way considered, is then a mere delusion, so long as the velocity is the same on the incline as on a level. Adhesion may, without doubt, fail oftener on an incline than on a level, (without speaking, be it understood, of the case where the steam might be carried to a higher pressure), on account of particular local conditions, of an habitually less favourable state of the rails; but the incline, once more, has nothing to do with it (216).

381. *Minimum speed for which the adhesion due to the weight of the engine*

suffices. — Thence this question: up to what minimum of speed does the adhesion suffice?

It is a question, of course, of the practical fact, of the locomotive such as it is constructed now-a-days, that is to say specifically as light as possible. It is clear that examples of very reduced speeds must be looked for specially on lines with steep gradients, seeing that thereon above all the interest is to adopt a low speed.

On the inclines of one in 66,6 on the line from *Rognac* to *Pertuis*; one in 50 on the line from *Mouchard* to *Pontarlier* (passage of the Jura by the *Val de Travers*) and on the line from *Saint-Rambert* to *Annonay;* one in 40 on the line from *la Levade* to *la Bastide;* one in 38 from *Tarare* to *Amplepuis* and *vice versâ;* one in 33,3 from *Saint-Michel* to *Modane*, where the speed adopted for the goods trains is, as we have seen, 9 miles an hour, etc., the working of the line is not hindered by slipping, on condition of using sand at need.

It can be therefore admitted that under the same conditions of climate, adhesion perfectly suffices up to nine miles an hour. It is even believed that a much less speed than that may be relied on. We have cited (199) the example of the Rhenish railways where 6 miles an hour is admitted, and that on coal lines, and therefore with but moderate adhesion.

This speed so low has for consequence (and it is that which requires particular arrangements and is the ground of the competition) the necessity of renouncing the direct action of the connecting rod on to the driving axle. In principle, it would no doubt be sufficient, in the case of an engine made for working at the ordinary slow speeds of from 9 to 12 miles an hour, to reduce the diameter of the wheels in proportion. But without taking into account the enhanced resistance to rolling of the engine, the thing would be impossible, for portions of the mechanism, especially the big end of the connecting rod, would then go down as low as the permanent way. If, in order to keep the diameter of the wheels sufficiently large, it were desired to reduce the number of revolutions, it would be necessary in consequence to increase the volume of the cylinders, seeing that, on the one hand the steam produced would be expended by a less number of strokes of the piston (and that without modifying the expansion, an essential condition of economical traction), and as on the other hand, the elements must be proportioned in such a manner that the factor $\frac{d^2 l}{D}$ of the effort of traction, may increase inversely as the speed.

This increase in the volume of the cylinders, obtained by increasing the

diameter, or lengthening the stroke, or by both, is equally impracticable beyond a certain limit. If the increase were principally effected by an increase of diameter, the velocity of the piston would be too low, the draught defective, the production of steam inefficient and the clearance spaces exaggerated. If it were done principally by the stroke, the drawback mentioned above of a crank too large for the wheels, would be encountered.

Thus in very slow running engines, the equality between the number of revolutions and the number of double strokes of the piston has to be given up, the transmission by gearing admitted between the shaft worked by the pistons and the driving axle : an arrangement which reduces the velocity of rotation of the latter, in a suitable ratio. *Chaplin* and *Co*, of *Glasgow*, build, for contractors, small locomotives for steep gradients; they have four wheels coupled, the boiler and the cylinders vertical, and a transmission by gearing; characters found in many engines which date as far back as the early days of railways, but appropriated to the special conditions in question at the present time. Moreover, as we shall see by interesting examples, gearing, although but moderately satisfactory, can, strictly speaking, be admitted as a means of transmission between parallel axles, in locomotives as well as in other engines. But there remains the question of adhesion (199). How will that of the engines of the Rhenish lines suffice to transmit the effort of traction corresponding to so low a speed, above all under conditions ordinarily so unfavourable of the coefficient of adhesion on the collierys lines, for which the engine is particularly intended? The program certainly provides that at need the weight of the tender shall be rendered adherent. Admitting that to be sufficient, a tank-engine would have been much simpler; but on account of the sharpness of the curves, the number of wheels has been fixed at four only, which prevents the fuel and water being placed on the engine itself. It is probable that for such an engine, the condition, general for ordinary speeds, of the maximum of specific lightness, would be departed from, and its weight carried to the limit compatible with four points of support, a limit which may be forced without scruple, when the speed is very low.

382. The *Méditerranée* lines offer indeed two examples of speeds fixed at 6 miles an hour, and that for ordinary engines with six wheels coupled, about 4 ft, 25 in diameter. The line from *Aubagne* to *Valdonne* which serves the *Fuveau* lignite basin, has gradients which are as high on the last 4 miles out of *Auriol*, as one in 66,6, one in 50, one in 45,7, with curves of 220 yards. On this length the speed of the goods trains is fixed at 6 miles

ascending, where the engine has little but empty waggons to draw, and 9 miles descending. But as the mean load is 93 tons, which the engines in question draw easily on the same gradients, there is nothing to be deduced from this velocity of 6 miles an hour. With a load corresponding to a mean speed of 6 miles, the engine would want adhesion even under the climate of *Provence*. The second example is to be found on the line from *Rognac* to *Pertuis*, where the mean velocity of the goods trains is fixed at 6 miles an hour on the incline of one in 66,6 from *les Milles* to *Aix*. This low speed is the effect of the double slackening: at the foot of the incline, to take on the auxiliary engine (375); and at the summit, for the stoppage at *Aix*. The loads of the engine are only calculated, however, as we shall see presently, starting with a minimum velocity of 9 miles an hour.

383. On lines with steep gradients, if a lower velocity is found expedient, than that for which the adhesion suffices, with engines placed under ordinary conditions of relative weight, deliberately exaggerating this weight would never be dreamed of; it should on the contrary, and especially in that case, be reduced by every possible means; the adhesion being then radically insufficient, recourse must be had, and then only, to special expedients for completing the adhesion, or for replacing it by a point of support, which shall not, like it, disappear under the tangential pressure of the driving-wheels. We shall study these expedients presently; but it will be well to dipose now at once of the would be solutions, which start upon the pretended want of adhesion, alleged in an absolute manner, without reference to the speed.

If the engines which are running on inclines of one in 33,3, one in 28,6, one in 25, weigh 40 tons, 50 tons and beyond, it is solely, say the partisans of these solutions, because their adhesion must be raised to the necessary figure; and the principle once laid down, the consequence thereof is quite simple. If one way or another the adhesion could be managed to be rendered independent of the weight, every thing goes right. No more heavy engines; thence, no more costly roads rapidly destroyed. Light motors suffice for every thing, and the ratio of the useful load to the dead weight has been improved as if by magic!

It is singular that similar heresies should be still maintained at this day. And indeed if they were only so by persons unacquainted with notions of engineering! They will not see that these engines from 50 to 60 tons, are not only constructed for steep gradients, but also for drawing on a level; that if engines get heavier and heavier, it is that a more considerable

amount of work is required from them; that the engines must run either with an equal load at higher speeds, or at an equal speed, drawing heavier loads; that if they are very heavy, it is that they must be at the same time both very powerful and very solid, and that their weight is far from having progressed in the same ratio as their power. Very far from designedly overloading them with a view of adhesion, they are built, on the contrary, as light as their power permits. Paring down, that is the word, is practised on all the partial weights. Substitution of wrought for cast-iron for the naves of the wheels, cast-steel for wrought iron for the parts of the machinery, steel instead of iron plates for the boiler, multiplicity of tubes (sometimes excessive), etc.... every thing has been put in request to reduce the relative weight, or the weight referred to the unit of heating surface; that is to say that the adherent weight, and consequently the adhesion itself, *are as low as possible*; and in fact, at the velocities which are not yet gone below on the great lines, this adhesion is sufficient.

Without doubt, if we succeeded in making engines lighter than the present ones, without losing either power or solidity, the adhesion due to the weight would become insufficient, and it would certainly be necessary, at the low speeds for which it still now suffices, either to have recourse to another means of transmitting the effort of traction, or to give up the benefit of the relative lightness. But the locomotive has been brought to such a simplicity of organs, the water stored in the boiler is so reduced, the evaporation per unit of surface so abundant, that a notable reduction of weight is scarcely possible without an entire revolution in the mode of production of the mechanical work.

The inventors who seek to realise the independence of the weight and the adhesion, are thus most completely in error, when they affirm that, thanks to that independence, the weight of locomotive engines could be greatly reduced: it is quite the contrary. Whatever be the artifice brought to bear to find a point of support beyond the adhesion due to the weight, it always requires the application of new parts to the engine, the weight of which can be by no means neglected.

If it be desired, in spite of experience, of evidence even, to profit by the independence of the weight and the adhesion to exaggerate the relative lightness of the engine, it happens, as we shall presently see by an example (the first engines of Mount-Cenis), that the parts of the machinery and of the frame, being too slender get out of shape, and break.

M. *Fell's* engine (423 and following) is nothing else than an ordinary engine utilising like the rest, the adhesion due to its weight, and utilising

as well, by the contrivance which is its only special characteristic, the adhesion due to a lateral pressure. This second source of adhesion requires special organs, which of course involve additional weight.

The engine provided with these special organs is not then lighter but heavier, inevitably, all things besides equal, than one which utilises only the adhesion due to its weight. Its passive resistances are also much more considerable. Without doubt, that does not condemn the system; this surcharge of weight is necessary in as much as the low speed at which the engine has to utilise its power, renders the adhesion due to the weight insufficient. But by what singular hallucination can be presented as effecting an enormous lightening, what conduces on the contrary to an inevitable increase of weight? Supposing that some day, the speed at which an engine with double adhesion travels is found too low, and the speed be adopted corresponding to the simple adhesion of the weight. What would be done? One simple thing. The special apparatus for the supplementary adhesion independent of the weight would be removed, and thus an ordinary engine would be arrived at. Would this suppression, perchance, have rendered it heavier? It is however to this that the assertion comes, of those pretended inventors, who see in the independence between the adhesion and the weight of the engine, the incontestable principle of an enormous reduction of this weight.

But if the expedients which realise this independence can in no way effect a reduction in the weight of the engine; if they have by no means the property which some of their inventors and partisans so readily attribute to them, they have another which comes out from what precedes, and which distinctly defines the logical conditions of their application: the normal velocity diminishing, and the tractive effort increasing inversely, the adhesion, which is constant, becomes insufficient. It is thus from this point out, and then alone, that the contrivances in question are expedient. They allow the reduction of speed to be carried farther, to obtain from the engine a more considerable tractive effort; and on that account they are applicable to very heavy gradients, on which they allow the load drawn to be increased and thus to improve the ratio, otherwise most unfavourable, between the useful load and the dead weight. And yet, this improvement is not so great as what whould result from the simple reduction of speed, the weight of the engine, and its own particular resistances being increased by the special organs which it then requires.

384. If the expedients which allow of the velocity being much reduced

may extend the field of application of the locomotive specially on inclines, they have however but a rather restricted importance; the objection arising from the smallness of the useful effect is reduced, but still exists.

During many years, one in 200 was looked upon in France, as the limit admissible on locomotive lines. Then little by little this limit was exceeded by the force of things; and the locomotive still remaining, in spite of its disadvantages which began to show up as the inclination increased, the most practical of the solutions, these existing figures have been reached : one in 40, one in 33,3, and beyond; limits at once too low to overcome the difficulties of the ground, without expenditure often excessive, and too steep to avoid working expenses not less excessive. If, for want of something better the locomotive does tolerably well on gradients of from one in 33,3 to one in 28,6, these are certainly out-of-the-way conditions contrary to the very nature of a motor itself participating, as living ones do, in the movements it imparts.

The limit of one in 200 was laid down arbitrarily. It was also connected with considerations of security; wrongly, for it is easy to put that out of the case, even far below that limit. But as long as it could be stuck to without too much expense, and particularly for lines of large traffic, it was wise to adhere to it, or to go as little as possible beyond it. Such gradients, in effect, do not seriously affect the conditions of traction. The load of the engines may be regulated almost without taking them into account; the engines pass over them by a simple reduction of speed, combined at need, with the use of their excess of power. Beyond, it is not the same thing; the compensation of the increase in the effort of traction by a correlative reduction of the speed, would lower the latter to a point at which the adhesion would become insufficient, admitting, on the one hand, that the engine could always develop the same amount of work, and on the other, that the working of the traffic could put up with a speed so reduced. We shall return just now with details to this point.

At the same time that great sacrifices were made to keep down the limit of the gradients, the same was done, and with very just reason, with regard to raising the radius of the curves. 875 yards, 656 yards by exception, such was the minimum radius of curvature on the running line, excepting of course the curves of sidings and crossings. But the day came when both, gradients much steeper, and curves much sharper, had to be resignedly accepted.

This could be done with less regret for the curves, as these have less drawbacks on a line with steep gradients, then on a line sensibly level.

An engine of given power and weight draws on the first a much less load than on the second; and consequently, the increase of resistance due to the curve, an increase nearly proportional for the same rolling-stock, to the weight of the train, is less also.

On the other hand, one of the disadvantages of sharp curves, that is to say the reduction of speed imposed on fast trains by reasons of security, does not affect the lines on which high speed is already prohibited by the steepness of the gradients. Curves of 220 yards, for example, which should in general be rejected absolutely from a line with a flat section, may be allowed without much trouble on a line with steep gradients, on the condition at any rate of avoiding as much as possible, the coincidence of the steepest gradients with the sharpest curves.

There is without doubt a chief interest in avoiding very stiff inclines, unless they are very short. But so long as the minimum, which it is impossible to get rid of, is already high, a little extra stiffness should not be hesitated at, if there would result, as often happens, a notable economy in the construction of the line. Great care must be taken for example, not, in order to lower the limit from one in 50 to one in 66,6, to involve sacrifices, which might be perfectly justified, if the question were from one in 100 to one in 200. It is the proportional, and not the absolute lowering of gradients that must be looked to. So long as, above all, limits can be kept within, such as do not seriously modify the conditions of traction, the same engine being able to draw nearly the same load as on a level, by a simple reduction in speed (387) it is expedient to do so even at the cost of considerable sacrifices. But when a change in the conditions of the traction becomes inevitable, the same reduction of the gradients has not the same value, and it would be a mistake to buy it so dearly.

But the rapid decrease in the loads drawn when the inclines increase, must never be lost sight of. An engine with eight wheels coupled, of the *Méditerranée* for example only draws on an incline of one in 33,3, at the velocity of 9 miles an hour, the *one-fifteenth* of the load which it draws at the same speed on a level.

Here is the law of this decrease of load :

Engines with eight wheels coupled (2.501 to 2.530)																	
	Inclines one in:	0	333	200	143	111	90	77	67	59	53	48	44	40	36	34	33
	Loads drawn at 9,32 miles an hour....	tons. 2.330	tons. 1.170	tons. 865	tons. 680	tons. 556	tons. 467	tons. 400	tons. 348	tons. 306	tons. 271	tons. 243	tons. 218	tons. 198	tons 180	tons. 164	tons. 157

As to the influence of the velocity, the load of 150 tons, at the speed of 9 miles, falls to 57 tons at the speed of 22 miles an hour.

385. *Rapid destruction of the rails on inclines. Their more rapid destruction on the down way.* — This useful effect so restricted, is not the only economical disadvantage of heavy gradients worked by locomotives. There has to be added the prompt destruction of the rails. With equal traffic, this is much greater than on a level. Whether recourse be had, in effect, to dividing the trains, to auxiliary engines, or to special engines more powerful and heavier, the result is always to multiply, for equal traffic, the number of journeys per ton of the engine.

The aggravation, at the same time, does not affect both the lines equally. If the traffic be the same both ways, the fatigue resulting from the normal pressures is the same, and the sum of the tangential actions is less for the descending rails than for the ascending, seeing that the effort of traction on the ascent, is the sum of the parallel components of the weight and the resistances, while the retarding force on the descent is only their difference. It thus seems that, for an equal movement both ways, and *a fortiori* for a preponderance on the ascent, the wear of the rails should be more pronounced on the ascending rails than on the descending. It is however the contrary which takes place; and the inequality is sometimes very marked.

There is, therefore, in the mode of action of the retarding forces applied to the trains, a special cause of wear, and the intensity of the tangential pressures is not everything.

This cause (which of course diminishes the use of the counter-steam without reversing the driving wheels), is nothing else than the frequent skidding of the tender and van wheels by screwing the brakes too tight, and sometimes by the use of brakes acting directly on the rails. The moment there is sliding, be it under the smallest pressure, there is wear; a driving-wheel, although heavily loaded and exerting a considerable tangential effort, wears the rails very little, as long as there is no slipping; but even slightly loaded, it wears them rapidly whenever it slips; and it is often the small load precisely, which determines slipping.

This point was contested by M. *de Freycinet*, *Ingénieur des Mines*, then engineer on the *Midi* lines:

" The slipping of the driving wheels", says he (*), " is only, it is true, accidental, but

(*) *Des pentes économiques sur les chemins de fer*, p. 76 and 77.—*Paris, Mallet-Bachelier*, 1861.

the tendence to slip and the tangential effort which results therefrom is perpetual. It matters little that the *presence of this effort* shows itself in the form of slipping; provided that it exists in the same degree, the results are the same. Between *a wheel which advances by slipping*, and a wheel which advances by turning in virtue of adhesion, there is no other difference, from the point of view of the wear of the rails, than that itself of the efforts which come into play in the two cases."

It seems proper to set right such an error, when it emanates from a distinguished engineer. This *perpetual tendency to slipping* producing the same effect as slipping itself; this pretended equivalence of the *tendency*, and of the *fact*, are manifestly in contradiction with daily experience, not less than with reasoning. If a direct proof of this were necessary, here is one taken from the beginning of the working of the *Giovi* line. While waiting for the first twin engines with four wheels, engines with six wheels were employed, to which skid brakes were put, placed only between the front and middle wheels. It was soon found that the wear of these two pairs of wheels was much more rapid than before, while that of the hind-wheels remained the same. Now the action of the brakes had for effect to greatly reduce the load on the two pairs of front wheels, increasing, at the same time, a little, that on the hind wheels. For free wheels, simply bearing, the wear should have evidently decreased with the load. In this case, on the contrary, it increased, because the slipping resulting from the connection of the six wheels together and of the inequalities of the diameters were especially on those least loaded.

Moreover, the increase in the wear of the rails of the descending pair of rails, is on the *Giovi* line in particular, beyond all question; and the cause is no less certain than the fact itself. They have even gone so far as to make out that the total expense of a train is, on this account, as much in descending as in ascending. But M. *Biglia* (*) shows this to be an aggravation; the increase in the wear of the rails on the descent is far from compensating for the consumption of fuel on the ascent. It is besides entirely to reduce this wear that the skid brakes have been removed from the train-engines still in service. This removal has attained its end; yet however it has in no way modified the sum of the tangential reactions.

386. *Very unequal utilisation of the boilers of engines running at different speeds.* — If we take facts, such as they are presented to us by the working

(*) *Réfutation*, etc.

of railways as a whole, we ascertain that, for equal power (that is to say in general for boilers of the same type, with equal heating surfaces) an engine at a low speed, consumes in the unit of time, much less fuel, and consequently produces much less steam and much less work than an engine at a high speed.

There is evidently no necessary reason why this should be so. Let us suppose, to place ourselves under well defined conditions, two engines identical as regards boiler, as regards cylinders, as regards machinery, differing only by the diameters of their driving wheels, driven in the same manner, and working at the same pressure, with the same number of revolutions, and consequently running at speeds proportional to the diameters of their wheels.

The expenditure of fuel and the production of steam will be the same in the two cases, for every thing is identical, save one point: the influence of the velocity of translation on the direct absorption of air into the fire-box; but we know that this influence may very nearly be neglected, against that of the forced draught by the blast. The work available at the circumference of the driving wheels will thus be sensibly the same in the two cases; only there will be an exchange, a compensation between the two factors, the slow engine giving a tractive effort amplified in the inverse ratio of the velocities. This effort must of course be transmissible by the intermedium of the adhesion, and we suppose in this case that the limit of speed below which this condition ceases to be fulfilled, is not reached.

The different types of engines do not realise, quite, the condition we have admitted, that of the proportionality of the normal speeds to the diameters of the wheels. But it is not the less true that the evaporative power ought to be sensibly independent of the speed, within the limits between which that varies in practice, from one type to another.

If then, the proportionality of the consumption, of the production of steam and work, to the heating surface, is not realised in general; if on most lines, engines at a low speed produce less steam per units of heating surface and time than engines at a high speed, it is simply because such is desired. It is that the fire is pushed much less actively in engines running at a low speed, than in those running at a high speed, and from the first, much less work is required than they can and ought to produce: an uneconomical position, which nothing justifies, but which is consecrated by long habit. By utilising but very uncompletely the power of slow speed engines, both the expense of traction (properly so called) per ton mile, and the necessary staff of engines are wantonly increased.

The writer of these pages said in 1854 (*):

" The goods engines of 1.076 square feet of heating surface of the *Lyons* line, only consume from 28,4 to 30,0 gallons of water per mile, under the conditions of regular working, that is to say drawing, inclusive of their own weight and that of the tender, 350 tons on gradients of one in 200, at a speed of 15,5 miles an hour. This comes to 4 lbs, 3 of steam per hour and per square foot, that is to say notably lower than the ordinary figure of stationary boilers with flues, in which however much less water is carried over with the steam. »

" .... Before increasing at any price, as is sought to be done at present, the heating surface, *what there is already should be better utilised*, were it necessary, on that account, to sacrifice a little fuel. *In one word, goods-engines should be worked in the same way as passenger-engines are.*"

This appeal, even to-day, would still be without effect, if the *Méditerranée* company had not, a dozen years later, laid down at last, the principle of the invariability of production of steam boilers of the same type, whatever might be their velocity of translation.

For some years now, this company has thus decided to obtain from its goods engines the work that can and ought to be produced by them. For all the engines without distinction, the gross normal evaporation has been fixed at the same figure: 8 lbs, 2 per square foot per hour. The only exception, and that is quite natural, is for one single type: the engine with eight wheels coupled; on account of the length of its tubes (17 ft, 6) and the less evaporation per square foot, the figure has been reduced to 7 lbs, 1.

The consequence of this step has been an increase of more than 30 per cent in the loads of the goods-engines, and the stock has thus been able to meet both the development of the lines, and of the mileage run.

By utilising the engines more completely, and working nearly to the limit of their power, discretion has been obliged to be left to the local superintendents, with respect to the cases in which the regulation-load might be too heavy and might, under unfavourable atmospheric conditions, interfere with the service.

The drivers in spite of the increase of work thrown on them by more careful and continuous attention to the fire, accepted without very great complaints, a reform the justice of which they recognised; and if later any complaints arose, it was in support of a discussion which changed its character, and exceeded the limits of a simple professional contention. The

(*) *De la construction des locomotives très-puissantes et à petite vitesse.* Annales des mines, 5th series, vol. VI, 1854, p. 365.

system has been accepted without trouble by a numerous staff, whose habits however it disturbed, and who are disposed to resenting innovation as an attack on their interests. But the drivers felt the measure to be right, if it imposes a little more work on them, it in no way wrongs them. It is of course unnecessary to say that the allowances of fuel were raised, in proportion to the extra work done.

The results obtained scarcely allow a doubt to be entertained on a principle which, almost self evident, has received such a confirmation from facts. It is still however contested

"In fact", says M. *Jacqmin* (*), "it has been ascertained on the Eastern of France, that the production of steam per square foot of total heating surface was, for engines running at a high speed as high as 8 lbs, 2, while with goods engines, no more than 5 lbs, 0 could be reckoned on. Experiments made on the *Orléans* line gave similar results."

We shall return to the experiments in question, and which are I believe, rather *observations* than *experiments* properly so called; statements of what is actually done, and not of what could be done.

If a little more is required at times from the goods engines, on the *Méditerranée*, than is warranted, if the running adopted lends itself in some points to criticism, the very principle of the reform is unassailable; and there is reason for surprise that an improvement indicated so naturally, so all important by its economical results, and so thoroughly sanctioned by practice, should not yet have triumphed over the empire of habit. If low speed engines produce much less than fast ones, it is, once more, because it is so desired; and for that position of affairs to end, it suffices for that result to be desired.

(*) *Des machines à vapeur*, vol. II, p. 270.

CHAPTER XI.

LOADS AND CORRELATIVE SPEEDS OF AN ENGINE ON A VARIABLE SECTION OF LINE.

387. If identical engines, differing only by the diameter of the driving wheels, and making the same number of revolutions, produce the same quantity of steam, and yield the same available work at the driving axle, the same engine can also have the same production at different speeds, but only within certain limits, and yielding an available amount of work increasing with the speed, because the expansion increases therewith. The same quantity of steam may be delivered by the cylinders, although the speed diminishes, the diminution of the total volume taken by the pistons in the same time being compensated for, by a longer admission, and by the greater density possessed in the cylinders, by the steam entering through less cramped orifices, and driving the piston slower. The energy of the draught remains perceptibly the same, the greater quantity of steam injected at each exhaust, compensating for the less number of beats. There is of course a limit; this constancy of the production is not rigorous, but it exists, practically, even below the minimum of velocity that the insufficience of the adhesion does not allow to be passed (381). On a rather flat line, an engine can, drawing the same load over the whole line, constantly utilise its power; the variations of the resistance corresponding to the changes in the gradients or the curves are compensated for by the variations, inversely, of the speed; but beyond a certain limit of inclination, the slackening of speed possible on the ascent, not being sufficient to furnish the necessary increase of the efforts of traction, the load must be reduced; and on the other hand, on the descent, the work to be developed is very slight, or even negative in order to prevent the risk of acceleration.

The correlative determination of the loads and the speeds of an engine on a given line, is an important and delicate point, which it is desirable to enter on in some detail. We shall take first for example, the work done in the rolling-stock and locomotive service of the *Paris* to the *Méditerranée* system, starting with the principle of the uniformity of evaporation for all the types, and for each type, between the limits of its usual speed.

Load sections. — Fictive gradients. — The basis of the work established for each type of engine, was above all, the division of the line into *load sections*, and the determination, for each of these, of a fictive section of the same length, but without curves, of uniform inclination, and equivalent to the real section, that is to say that the same engine would draw the same load in the same time, with a uniform velocity, lower than the real velocity on the flat gradients, and higher than the real velocity on the steep gradients of the section.

This determination necessarily implies the estimate of the resistance due to the curves, replaced in the fictive section by equivalent gradients. It requires also, as we are about to see (387) the knowledge of the resistance on a level and on a straight line. It takes into account as much as possible the circumstances of every nature which influence in one way or another, the necessary effort of traction, and which should, thence, be represented by a greater or less variation of the fictive gradient; it takes into account even of some conditions which influence, not only the magnitude of the effort, but the difficulty of producing it in a sustained manner. Thus the fictive gradient is reduced by diminishing the speed, and consequently the resistance, in the ratio of the incline; it is also reduced by making every use when possible, of the force of inertia for surmounting short inclines; *per contra* it is forced a little for the load sections which the engines only reach, according to the distribution of the depôts, after having already run a long distance, and when on that account the fire is in a less efficient state, the grate clinkered, the lubrication of the machinery less perfect, and the men themselves fatigued.

But the influence of the reduction of speed is by far the greatest; and that explains how the fictive incline is below the real one, at least on lines with large curves, although the first includes in addition the resistance due to the curves; it is that the latter does not compensate for the slackening.

It is clear that the more difficult the line is, the more desirable the division of the load sections becomes, establishing for each one a special fictive incline; but if several consecutive sections have to be worked by the same type of engine drawing the same load over all of them, this load should evidently be fixed according to the maximum fictive incline.

There is generally, for the same section, a fictive incline for each direction of running. The curves, in effect, introduce a resistance in one direction as in the other, greater indeed on the descent, because of the generally greater speed; and the variations of the real gradients act similarly, the

descent of the inclines not compensating for the ascent thereof. It is clear besides that the fictive incline, ordinarily different for the two directions, is the same if the two extreme points are on the same level, and if the distribution of the gradients is about the same in the two directions; and that, in the case of the levels being different, the fictive incline is less in the direction of the general descent than in the other.

On lines with steep gradients all one way, there is only a fictive incline on that way; in the other there is none. The fictive gradient represents the additional resistances due to the real gradients and curves, resistances only brought down by a systematic reduction of the speed: it is therefore essentially positive. When the sum of the additional resistances is nothing, the fictive gradient is also the same, whatever may be the inclination of the gradients, and the loads entered in the table, are those which correspond to a horizontal and a straight line.

They are found figuring equally for level sections, for the inclines of one in 120,5 from *Blaisy* to *Darcey* and to *Dijon*, as well as for those of 1 in 60 between *Grasse* and *Cannes*, of 1 in 40 at *Villefort*, of 1 in 38,4 at *Tarare*, of 1 in 37 from *Marseilles* to *la Joliette*, and of 1 in 33,3 at *Modane*, etc. (392). The condition which overrules everything on the descent on such inclines is to moderate the speed.

388. *Influence of the nature of the train.* — For the same load section, the fictive gradient is not the same for the different categories of trains. It is greater for goods trains than for ordinary trains; and greater for the latter than for the express.

This is easily explained. On the one hand, trains already slow on a level, have less margin than the others for taking advantage of the reduction of speed, and also to utilise even on the gradients, if there be room, the *vis viva* corresponding to the reduction. On the other hand, the resistance of the curves, in spite of the aggravating influence of the velocity on the increase of resistance which they impose on a given train, affects the slow running trains more, because they are generally much longer than the others.

The influence of the length of the train has already been mentioned (263). With equal weight, an empty train undergoes notably more resistance on curves than a loaded train, particularly, if as often happens, the long train is on two reverse curves at the same time. The fictive incline ought in this case to be a function of the length of the train; but in practice these refinements of calculation do not answer; they complicate, without being

of real use; and it is considered sufficient to adopt a mean load in the waggons.

To sum up, the determination of the fictive incline, is a delicate operation, somewhat arbitrary in its details, and requiring on that very account, an exact acquaintance with the resources an intelligent driver can fall back on with his engine, and one thoroughly familiarised with the line.

The fictive gradient equivalent to each load section for the two directions run in, and for each category of train, being established, the corresponding loads remain to be determined, for each type of engine, and for a pretty considerable range of speeds; and these require simply the knowledge of the resistance on a level for each speed, the resistance due to the incline being evident in itself.

389. — To give an exact idea of this operation, it is necessary to place under the eyes of the reader: 1. an example of the determination of the fictive equivalent gradients for the two directions run in, for one load section; 2. some of the tables called: *gross loads, expressed in tons, which the engines of the different types can draw on the load sections at different speeds.*

Here is first for the two directions run in, on the same load section, and for mean speeds from 9 to 43 miles an hour, the variation of speed on each part of the line, a variation determined by the condition of drawing throughout the maximum load:

Paris to Montereau.

Mean velocities in miles an hour		9,3	12,4	15,5	18,6	21,7	25	28	31	34	37	40	43
STATIONS.	GRADIENTS.	VARIABLE SPEEDS, MILES AN HOUR.											
Paris to Villeneuve-St-Georges	0	10,5	13,6	17	20	23	26	29	32	35	38	42	45
Villeneuve-St-Georges to Lieusaint.	1 in 200	7,5	10	12	15	19	22	25	28	31	34	37	40
Lieusaint to Melun	1 in 250	12	16	20	24	26	29	32	35	37	40	43	47
Melun to Thomery	1 in 200	7,5	10	12	15	19	22	25	28	31	34	37	40
Thomery to Montereau	1 in 200 0	12	16	20	24	26	29	32	35	37	40	43	47

Montereau to Paris.

Mean velocities in miles an hour		9,3	12,4	15,5	18,6	26,7	25	28	31	34	37	40	43
STATIONS.	GRADIENTS.	VARIABLE SPEEDS, MILES AN HOUR.											
Montereau to Moret	0 1 in 200	10,5	13,6	17	20	23	26	29	32	35	38	42	45
Moret to Thomery	1 in 200	7,5	10	12	15	19	22	25	28	31	34	37	40
Thomery to Fontainebleau	1 in 333	10,5	13,6	17	20	23	26	29	32	35	38	42	45
Fontainebleau to Bois-le-Roi	1 in 200	9	12	15	19	22	25	28	31	34	37	40	43
Bois-le-Roi to Melun	1 in 200	10,5	13,6	17	20	23	26	29	32	35	38	42	45
Melun to Lieusaint	1 in 200	7,5	10	12	15	19	22	25	28	31	34	37	40
Lieusaint to Paris	1 in 200 0	10	13,6	17	20	23	26	29	32	35	38	42	45

The two following tables give a complete example of the determination of the fictive inclines for the two directions run in on the same section, and under the operation of these three elements: 1. real inclines; 2. curves; 3. correlative variations of the speed and the section.

The part of the first element is evident.

We shall return to the part of the second when we treat of the resistance of trains; for the moment we shall suppose it known.

The sum of these two resistances, calculated for a portion at a constant inclination, is a fraction $\frac{1}{i}$; it is the sine of the inclination of the fictive incline, if the speed thereon is equal to the mean speed over the whole of the load section.

But we can imagine this gradient replaced by another of less inclination, $\frac{1}{\mathrm{I}}$, on condition of suitably reducing thereon also the speed.

Let: P be the weight of the train drawn, r the coefficient of resistance, on a level and on a straight line, corresponding to the velocity V of the train on the incline $\frac{1}{i}$; r' the coefficient corresponding to the velocity $\mathrm{V}' > \mathrm{V}$, on the gradient of inclination $\frac{1}{\mathrm{I}} < \frac{1}{i}$.

Tbp being the constant work done in the unit of time, we have:

$$\mathrm{T}=\mathrm{P}\left(r+\frac{1}{i}\right)\mathrm{V}=\mathrm{P}\left(r'+\frac{1}{\mathrm{I}}\right)\mathrm{V}',$$

whence

$$\frac{1}{I} = \frac{V}{V'}\left(r + \frac{1}{i}\right) - r' = K\left(r + \frac{1}{i}\right) - r'.$$

$\frac{1}{I}$ is the inclination such that the load drawn thereon at the velocity V', is drawn equally by the same engine on the incline $\frac{1}{i}$, on the condition that the velocity be reduced thereon by $V' - V$. This is then the gradient which can be substituted for $\frac{1}{i}$, on the condition of effecting that reduction of speed thereon; it is the *fictive gradient.*

If instead of taking the incline $\frac{1}{i}$ with a velocity already reduced to the value V, which ought to be kept up thereon, the train takes it with the velocity V', and if the latter is only reduced to the value V after the gradient $\frac{1}{i}$ of length l has been run over, the *vis viva* transformed into work is $\frac{1}{2}\frac{P}{g}(V'^2 - V^2)$, and the mean corresponding effort referred to the unit of weight $\frac{1}{2}\frac{(V'^2 - V^2)}{g\,l}$, diminishes by so much the resistance, or the fictive gradient, so that

$$\frac{1}{I} = K\left(r + \frac{1}{i}\right) - r' - \frac{V'^2 - V^2}{2gl}. \qquad (a)$$

Section from Paris to Montereau.

MILEAGE.	Lengths in miles.	GRADIENTS one in.		CURVES in yards.		RESISTANCE DUE TO CURVES in pounds per ton.						TOTAL RESISTANCE in pounds per ton.					
						Maxima.			Mean.			Maxima .			Mean.		
		Maxima.	Mean.	Radii.	Lengths.	Goods.	Ordinary.	Express.	Goods.	Ordinary.	Express.	Goods.	Ordinary.	Express.	Goods.	Ordinary.	Express.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
0 — 10	10	500	—10.000	1.203—2.187	5.140	2,64	1,50	1,21	0,55	0,31	0,24	4,41	4,41	4,41	0,33	0,08	0,02
10 — 13	3	250	250	1640	4.703	1,98	1,10	0,88	1,72	0,93	0,35	10,08	9,92	9,76	10,05	9,74	9,57
13 — 17	4	200	213	1.640—2.187	2.406	1,98	1.10	0,88	0,48	0,26	0,22	11,00	11,00	11.00	10,08	10,06	10,06
17 — 27	10	333	— 500	1.640—2.187	2.734	1,98	1,10	0,88	0,24	0,13	0,11	6,61	6,61	6,61	—4,17	—4,28	—4,30
27 — 34	7	200	300	1.094—2.187	3.609	2,98	1,65	1,32	0,62	0,35	0,29	11,00	11,00	11,00	7,96	7,69	7,63
34 — 37	3	0	— 300	1.203—2.187	2.843	2,64	1,50	1,21	1,10	0,62	0,48	1,48	0,82	0,66	—6,24	—6,72	—6,85
37 — 40	3	286	400	1.094—1.968	2.625	2,98	1,65	1,32	0,70	0,46	0,35	9,37	8,62	8,44	6,22	5,97	5,86
40 — 45	5	0	— 258	1.094—2.187	5.906	2,98	1,65	1,32	1,59	0,88	0,70	2,98	1,65	1,32	—6,94	—7,65	—7,78
45 — 49	4	500	6.666	1.312—1.968	3.390	2,47	1,37	1,10	0,97	0.53	0,42	4,41	4,41	4,41	1,30	0,86	0,75
0 — 49	49	200	5.556	1.094—2.187	33.455	2,98	1,65	1,10	0,75	0,42	0,35	11,00	11,00	11,00	1,15	0,81	0,75

FICTIVE GRADIENTS.

" The fictive gradients have for maxima limits the resistances comprised between miles 10—13 " and 13—17, and for minima limits the mean resistances over the whole section.

APPLICATION OF FORMULA (*a*) TO THE DETERMINATION OF FICTIVE GRADIENTS.

1st. *To the maximum resistance comprised between miles* 10—13.

" The mean velocity may undergo a reduction of 6 miles " for all trains; the coefficient K $\left(=\frac{V}{V'}\right)$ may take the " value 0,90 for express trains, and 0,85 for goods and " ordinary.

" All the trains being obliged to pass the *Corbeil* " junction slowly the last term of formula (*a*) relative to " effects of the force of inertia is zero.

" We have (*):

" For express: $\frac{1}{I} = 0{,}90\ (9{,}0 + 14{,}19) - 16{,}31$

$= 4{,}56$ pounds per ton $= \frac{1}{490}$

" For ordinary: $\frac{1}{I} = 0{,}85\ (9{,}0 + 10{,}08) - 13{,}00$

$= 3{,}22$ pounds per ton $= \frac{1}{695}$

" For goods : $\frac{1}{I} = 0{,}85\ (10{,}08 + 7{,}00) - 8{,}08$

$= 6{,}43$ pounds per ton $= \frac{1}{348}$.

2nd. *To the maximum resistance comprised between miles* 13—17.

" The mean velocity may undergo a resistance of 6 miles " for all trains, remaining the same as on the preceding " incline. The coefficient K may take the value of 0,85 " for express trains, and 0,82 for goods and ordinary.

" The last term is zero, as there is no variation in the " velocity.

" We have (*) :

" For express: $\frac{1}{I} = 0{,}85\ (11{,}00 + 14{,}01) - 16{,}03$

$= 5{,}22$ pounds per ton $= \frac{1}{430}$

" For ordinary: $\frac{1}{I} = 0{,}82\ (11{,}00 + 10{,}08) - 13{,}00$

$= 4{,}08$ pounds per ton $= \frac{1}{550}$

" For goods : $\frac{1}{I} = 0{,}82\ (11{,}00 + 7{,}00) - 8{,}08$

$= 6{,}68$ pounds per ton $= \frac{1}{335}$

" These values being superior to the numbers which represent the mean resistance over the whole " section, it is expedient to adopt for the expression of the fictive gradients :

" 1 in 444, 1 in 444, 1 in 333. "

(*) For explanation, see the page 542.

Section from Paris to Montereau.

MILEAGE.	Lengths on miles.	GRADIENTS one in. Maxima.	GRADIENTS one in. Mean.	CURVES in yards. Radii.	CURVES in yards. Lengths.	RESISTANCE DUE TO CURVES in pounds per ton. Maxima. Goods.	Maxima. Ordinary.	Maxima. Express.	Mean. Goods.	Mean. Ordinary.	Mean. Express.	TOTAL RESISTANCE in pounds per ton. Maxima. Goods.	Maxima. Ordinary.	Maxima. Express.	Mean. Goods.	Mean. Ordinary.	Mean. Express.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
49 — 45	4	0	— 6,666	1.312—1.968	5.140	2,47	1,37	1,60	0,97	0,53	0,42	2,47	1,37	1,10	0,64	0,20	0,09
45 — 40	5	200	258	1.094—2.187	4.703	2,97	1,65	1,32	1,59	0,88	0,70	13,08	12,07	12,07	10,01	9,41	9,24
40 — 37	3	200	— 400	1.094—1.968	2.406	2,97	1,65	1,32	0,88	0,46	0,35	11,00	11,00	11,00	—4,80	—5,05	—5,16
37 — 34	3	250	300	1.203—2.187	2.734	2,64	1,50	1,21	1,10	0,62	0,48	10,03	9,63	9,48	8,44	7,96	7,82
34 — 27	7	0	— 300	1.094—2.187	3.609	2,97	1,63	1,32	0,62	0,35	0,29	1,48	0,81	0,66	—6,72	—6,99	—7,05
27 — 17	10	200	500	1.640—2.187	2.843	1,98	1,10	0,88	0,24	0,13	0,11	11,00	11,00	11,00	4,65	4,54	4,06
17 — 13	4	0	— 213	1.640—2.187	2.625	1.10	0,88	0,48	0,26	0,22	0,00	0,00	0,00	0,00	—9,88	—10,01	—10,01
13 — 10	3	0	— 250	1.640—2.187	5.906	1,98	1,10	0,88	1,72	0,93	0,75	1,98	1,10	0,88	—7,10	—7,89	—8,07
10 — 00	10	200	10,000	1.640	3.390	2,64	1,50	1,21	0,55	0,31	0,24	11,00	11,00	11,00	0,77	0,53	—0,48
49 — 00	49	200	— 5,556	1.203—2.187	3.345	2,97	1,65	1,32	0,75	0,42	0,35	14,00	12,07	12,03	0,35	—0,04	—0,02

FICTIVE GRADIENTS.

" The fictive gradients have for maxima limits the maxima resistances comprised between miles " 45—38, 42—39, and 27—24, and for minima limits the mean resistances over the whole sections.

APPLICATION OF FORMULA (*a*) TO THE DETERMINATION OF THE FICTIVE GRADIENTS.

1st. *To the maximum resistance comprised between miles* 45—38.

" The mean velocity may undergo a deviation of 6 miles.
" The coefficient K may take the value 0,90 for the express, and 0,85 for ordinary and goods. Taking into " account the effects due to the force of inertia, we have (*) :

" For express: $\frac{1}{I} = 0{,}90(11{,}00+15{,}04)-16{,}03-2{,}75$

$= 4{,}66$ pounds per ton $= \frac{1}{480}$

" For ordinary: $\frac{1}{I} = 0{,}85(11{,}00+13{,}00)-13{,}00-2{,}02$

$= 5{,}43$ pounds per ton $= \frac{1}{412}$

" For goods : $\frac{1}{I} = 0{,}85(11.00+8{,}81)-8{,}81-1{,}32$

$= 6{,}70$ pounds per ton $= \frac{1}{334}$

2nd. *To the mean resistance between miles* 42—39.

" The mean velocity may undergo a reduction of 12 miles " for express, and 6 miles for ordinary and goods. The " coefficient K may take the value 0,88 for express, 0,77 " for ordinary, and 0,75 for goods. The last term is zero, " on account of the *Moret* junction. We have (*) :

" For express: $\frac{1}{I} = 0{,}88\ (12{,}03 + 11{,}09) - 16{,}03$

$= 4{,}31$ pounds per ton $= \frac{1}{519}$

" For ordinary: $\frac{1}{I} = 0{,}77\ (12{,}07 + 10{,}08) - 13{,}00$

$= 4{,}06$ pounds per ton = [illegible]

" For goods : $\frac{1}{I} = 0{,}75\ (14{,}00 + 6{,}06) - 8{,}81$

$= 6{,}32$ pounds per ton $= \frac{1}{354}$

3rd. *To the maximum resistance comprised between miles* 27—24.

" The mean velocity may undergo a reduction of 12 miles " for express, and 6 miles for ordinary and goods. The " coefficient K may take the value 0.88 for express and 0,80 " for ordinary and goods. The term relating to the force " of inertia is zero. We have :

" For express: $\frac{1}{I} = 0{,}88\ (10{,}01 + 13{,}07) - 16{,}03$

$= 4{,}28$ pounds per ton $= \frac{1}{523}$

" For ordinary: $\frac{1}{I} = 0{,}80\ (10{,}01 + 10{,}08) - 13{,}01$

$= 4{,}87$ pounds per ton $= \frac{1}{460}$

" For goods: $\frac{1}{I} = 0{,}80\ (10{,}01 + 7{,}05) - 8{,}81$

$= 4{,}67$ pounds per ton $= \frac{1}{470}$

" All these values being superior to the numbers which represent the mean resistances over the " whole section, it is expedient to adopt for the expression of the fictive gradients, the numbers :

" 1 in 444, 1 in 444, 1 in 333."

(*) For explanation, see the following page.

These two tables including the elements of the determination of the fictive inclines, equal in the two directions, between *Paris* and *Montereau*, explain themselves as regards most of the points. It will suffice to point out the following:

1. The figures of the columns 10, 11, 12 are deduced from those of columns 7, 8, 9, by multiplying the latter by the ratio of the development of the curve (column 6) to the total development (column 2).

2. The total maximum resistance (columns 13, 14, 15) is not in general the sum of the partial resistances, because the maximum gradient only accidentally coincides with the sharpest curve. Thus, on the second horizontal line, this coincidence takes place, the gradient (one in 250) being constant. For the other horizontal lines the maximum resistance is only generally the greater of the two individual resistances, gradient and curve.

3. The total mean resistance is the algebraic sum of the means. Thus 0,33 first number (column 16) is the sum of the figures $-\frac{1}{10.000} = -0,22$ pounds per ton (column 4) and 0,55 (column 10).

4. In the horizontal line of the totals, the mean gradient one in 5.556 is, not the mean of the figures of column 4, but, as is besides self evident, the difference of level between the extreme points, divided by the total development.

5. The fictive gradient, $\frac{1}{i}$, or the resistance due to inclines and curves, between miles 9,92 and 13,2, for example, would be equal respectively to :

9,86 = one in 227 for express	10,08 = one in 207 for ordinary	10,98 lbs. per ton = one in 207 for goods,

if the velocity were there equal to the mean velocity, for which the admitted resistances r' on a level and on a straight line are:

16,31 for express	13,00 for ordinary	and 8,82 lbs. per ton for goods.

But on account of the reduction of 6 miles for the velocity of the trains of the three categories, a reduction which brings down their resistances r, on the level and on a straight line to :

14,19 | 10,80 | 7,05 lbs. per ton (figures which we admit here, their discussion will come in its place),

the fictive inclines $\frac{1}{I}$ become : one in 431; one in 378; one in 346, as it follows:

In the formula: $\frac{1}{I} = K\left(r + \frac{1}{i}\right) - r'$, we have:

	K	r	$\frac{1}{i}$	r'	$\frac{1}{I}$
Express....	0,90	14,2 p. per ton.	9,7 p. per ton (col. 15)	16,31 p. per ton.	5,10 p. per ton.
Ordinary...	0,85	10,8 do.	9,92 do. (do. 14)	13,0 do.	4,6 do.
Goods.....	0,85	7,05 do.	10,08 do. (do. 13)	8,82 do.	6,35 do.

6. The odd trains (*Paris* to *Montereau*) are obliged to slacken when they come to the horizontal of *Villeneuve-Saint-Georges*, on account of the junction. They thus take, with a reduced speed, the up gradient on miles 9,92, 13,2, and cannot utilise thereon their *vis viva*. We see that this transformation of *vis viva* into work brings about, on the contrary, for the descending trains a very notable reduction of the fictive gradient, between miles 45,26 and 38,4. The same thing would take but for the *Moret* junction, between miles 42,2 and 38,5, and all the more as the reduction of velocity is in that case more considerable.

390. *Table of loads.* — It results from what has been said higher up (387) that to each of the load sections, into which the system of lines has been divided, there correspond two tables, placed facing each other in the book, and each relating to one of the two directions run in. These tables are evidently identical when the fictive gradients are the same in the two directions. Such is the case for the *Paris* and *Montereau* division, as we have just seen. It will be sufficient to reproduce one only of these tables.

FROM PARIS TO MONTEREAU and from Montereau to Paris. **Fictive Gradients :** 1 in 444 — For Express and Mails. — Ordinary. 1 in 333 — Goods.

Loads in tons, which the engines of the divers types can draw at different speeds.

SPEED IN MILES :	10	13	16	19	22	25	28	31	34	37	40	43	47	50
Uncoupled engines. Series:														
1 to 40 51 to 76 161 to 170 219 to 223	221	205	190	182	174	163	156	146	133	124	108	98	80	67
Engines with 4 wheels coupled. Series :														
101 to 145 286 to 337 351 to 383 522 to 563 586 to 618 841 to 850	333	310	287	263	239	215	191	166	144	122	104	90		
451 to 468	403	370	327	295	263	231	198	166						
506 to 521	310	287	258	233	203	177	157	135						
146 to 160 564 to 585 631 to 645	305	283	264	255	237	217	198	176	158	138				
619 to 630 701 to 840 951 to 982	405	377	353	326	302	276	250	223	196	168				
Engines with 6 wheels coupled. Series :														
1.001 to 1.054 1.244 to 1.267 1.309 to 1.326	470	440	384	271	258	245	232	202						
1.101 to 1.150 1.224 to 1.243 1.268 to 1.308 1 327 to 1.364 1.397 to 1.400	505	475	438	402	367	331	295	258						
1.201 to 1.223	334	310	278	251	224	197	170							
1.401 to 1 800 2.000 to 2.006	635	590	525	464	397									
1.901 to 1.986	391	318	260	215										
1.998 to 1.999	840	770	680											

This table also requires some explanations, which will be equally applicable to all the other load sections:

1. A great inequality as regards the influence of the velocity on the diminution of the loads, is to be remarked between the engines of the first group (wheels free), and the others. Thus, the first which only draw 221 tons at 9 miles, still take 98 tons at 43 miles, while those of the six first series of the second group (four wheels coupled) which draw 333 tons at 9 miles, only take 90 tons, that is to say less than the first, at 43 miles.

This apparent anomaly, of a less rapid diminution of the loads for engines with uncoupled wheels can be easily conceived. As long as the speed is too low, an engine with small adherent weight, cannot draw the load corresponding to its power, to its heating surface; it is then the condition of adhesion which fixes the load entered in the table. The speed increasing, the effort of traction corresponding to the effective work diminishes, and ends by falling below the adhesion; the engine is then under normal conditions, and is able to take the load corresponding to its dynamic power: a position which engines with total adhesion attain, as soon as their speed goes on to 9 miles an hour.

In all the range of speeds where the effort of traction is fixed by the condition of adhesion, that effort is constant, and consequently the decrease of the loads is only the consequence and the expression of the influence of the velocity on the resistance.

The comparison of the engines with four wheels coupled and those with all coupled, leads to similar consequences. The engines of the series 1.101 and following draw, at 9 miles an hour, notably more than the series 619 and following: 470 tons instead of 405; and notably less at 30 miles: 202 against 223. At 9 miles, the first are able to use their whole power, while the others are not able to do so; they have not enough adhesion. But at a sufficient speed, about 18 miles, they resume the superiority which their greater heating surface assigns to them.

2. The loads are only inserted in the tables up to a certain velocity, variable according to the series: maxima for uncoupled engines, less, with however some oscillations, for four wheels coupled; less still for the six and the eight wheels coupled engines.

This is perfectly natural. There would have been no use in calculating, for one type of engine, the loads corresponding to velocities which that type ought never to reach.

As to the oscillations, the irregularities which the diminution of the limit-speeds presents, going from the top of the table downwards, they arise from the fact that the velocity does not affect equally the stability, maintenance, and useful effect of several types of engines, placed however under the same conditions as to coupling. Certain types with four wheels coupled are favourable, as we have seen, to the highest values of the speed, 43 miles and beyond, while for others, 36 miles is the utmost, and for others still, 30 miles an hour. The same remark applies to the engines with six wheels coupled, some of which can go so high as 30 miles an hour, while others must be limited to 16. We see besides as a general and quite simple fact,

that the maximum velocity figuring in the table, diminishes as the fictive gradient increases.

As to the minimum velocity, it may be asked why, instead of being always the same, 9 miles an hour, it does not vary from one type to another, like the maximum velocity; and if the engines with uncoupled wheels, the tractive power of which is relatively so small, at 9 miles an hour, really work under these conditions. It does happen so, in effect, but the least possible. The necessity may accidentally arise, from want of other engines, of working goods trains at a very low speed by engines with uncoupled wheels; but, speaking truly, an engine with uncoupled wheels running at a regulation velocity of nine miles an hour is as little to be met with, as an engine with six wheels coupled running at 37 miles an hour.

The figures of these tables, compared with the heating surface of the different series of engines, give the numerical measure of the advantages obtained by the total or partial coupling of the wheels, of the proportion in which it permits the load to be increased at low speeds, so extending the field of application of the engines, and reducing their specialisation; and this without taking into account its utility from the point of view of starting and getting up speed.

391. *The division in load sections results more from the organisation of the trains than from the line.* — The division of a line into load-sections results evidently, both from the conditions of the trace of the line (track) and the conditions of the traffic.

The more short trains there are, the more expedient it is to push far the division into sections. Thus, a train which would only run between *Paris* and *Villeneuve-Saint-Georges*, and the composition of which would be determined according to the table of the *Paris* and *Montereau* section, to which this portion without inclines belongs, would have too small a load; there would be room in that case, if partial trains were to be established thereon, to make a *special load-section* for them. This consideration explains what seems to be at first arbitrary in settling the division in question. Thus, at the passage of the summits, sometimes the two inclines downwards are comprised in the same section, sometimes each of them forms a distinct section. The crossing of the *Tarare* mountain is in the first case, that of *Blaisy* is in the second. It is that every train starting from *Amplepuis* goes as far as *Tarare*, and reciprocally; while there are trains starting either from *Darcey*, or from *Dijon*, which are rearranged at *Blaisy* and there take on the load which suits the rest of the run they have to do.

The section from *Amplepuis* to *Tarare* offers, as does that from *Paris* to *Montereau*, but under conditions of trace very different, an example of the equality of the fictive incline in both directions, on account of the near equality of level between the extreme points, as well as of the distribution of the inclines. The following table, from *Amplepuis* to *Tarare*, is therefore identically applicable to the reverse direction, from *Tarare* to *Amplepuis*.

FROM AMPLEPUIS TO TARARE *and from Tarare to Amplepuis.* **Fictive Gradients : 1 in 45. . .** For Express and Mails. — Ordinary. — Goods.

Loads in tons, which the engines of the divers types can draw at different speeds.

SPEED IN MILES.	10	13	16	19	22	25	28	31	34	37	40	43	47	50
Uncoupled engines. Series ;														
1 to 40 51 to 76 161 to 170 219 to 223	17	16	15	14	13	11	10							
Engines with 4 wheels coupled. Series :														
101 to 145 286 to 337 351 to 383 522 to 563 586 to 618 841 to 850	48	47	44	40	35	29	24							
451 to 468	65	62	55	47	39	32	26							
506 to 521	42	40	36	31	25	19	14							
146 to 160 564 to 585 631 to 645	37	36	35	33	31	27	23							
619 to 630 701 to 840 951 to 982	62	60	58	56	50	44	37							
Engines with 6 wheels coupled. Series :														
1.001 to 1.054 1.244 to 1.267 1 309 to 1.326	79	76	67	57	48	40								
1.101 to 1.150 1.224 to 1.243 1.268 to 1.308 1.327 to 1.364 1.397 to 1.400	83	81	78	71	63	55								
1.201 to 1.223	48	47	42	36	29	23								
1.401 to 1.800 2.000 to 2.006	114	111	102	90										
1.901 to 1.986	77	63	51											
1.998 to 1.999	153	146	132											
Engines with 8 wheels coupled. Series :														
2.501 to 2.530	230	195	156	125	96									

In the same way, two tables are sufficient for the two sections which rfom the crossing from *Verrey* to *Dijon;* the fictive inclines are, in effect, the same (one in 200 for express, and one in 166 for ordinary and goods-trains) for the ascent of the two sides, *Darcey-Blaisy* and *Dijon-Blaisy.* It is the same thing for the descent from *Blaisy*, either towards *Darcey*, or towards *Dijon*, where the fictive inclines are zero.

FROM DARCEY TO BLAISY *and from Dijon to Blaisy.* **Fictive Gradients** : 1 in 200 For Express and Mails. — Ordinary. 1 in 166 — Goods.

Loads in tons which the engines of the divers types can draw at different speeds.

SPEEDS IN MILES :	10	13	16	19	22	25	28	31	34	37	40	43	47	50
Uncoupled engines. Series :														
1 to 40 51 to 76 161 to 170 319 to 223	133	125	118	115	112	108	104	98	91	85	74	63		
Engines with 4 wheels coupled. Series :														
101 to 145 286 to 337 351 to 383 522 to 563 586 to 618 844 to 850	210	199	187	173	159	145	131	110	100	83	72	61		
451 to 468	257	240	215	196	177	157	137	119						
506 to 521	194	183	167	152	137	122	106	92						
146 to 160 564 to 585 631 to 645	189	179	170	162	154	146	137	122	110	96				
619 to 630 701 to 840 951 to 982	256	244	232	218	204	189	174	155	136	120				
Engines with 6 wheels coupled. Series:														
1.001 to 1.054 1.244 to 1.267 1.309 to 1.326	303	287	254	231	208	185	161	141						
1.101 to 1.150 1.224 to 1.243 1.268 to 1.308 1.327 to 1.364 1.397 to 1.400	323	308	290	270	249	228	207	182						
1.201 to 1 223	211	199	181	165	149	133	116							
1.401 to 1.800 2.000 to 2.006	409	389	352	313	273									
1.901 to 1.986	256	211	174	145										
1.998 to 1.999	545	505	455											
Engines with 8 wheels coupled. Series :														
2.501 to 2.530	762	643	525	434	348									

FROM ST-MICHEL TO MODANE. **Fictive Gradients :** 1 in 38 For Express and Mails; — Ordinary. 1 in 35 — Goods.

Loads in tons which the engines of the divers types can draw at different speeds.

SPEED IN MILES :	10	13	16	19	22	25	28	31	34	37	40	43	47	50
Uncoupled engines. Series :														
1 to 40 51 to 76 161 to 170	6	5	4	4	3	3	2	1						
Engines with 4 wheels coupled. Series :														
201 to 230	43	42	40	36	32	28	25	17	12	8				
101 to 145 286 to 337 351 to 383 522 to 563 586 to 618 841 to 850	32	31	30	26	22	18	15	11	8	4				
451 to 468	47	45	39	33	27	22	17	13	9	4				
506 to 521	28	26	23	19	15	11	7	3						
146 to 160 396 to 400 564 to 585 631 to 645	23	22	21	20	18	16	14	10	8					
619 to 630 701 to 840 951 to 982 997 to 1.000	43	42	41	38	34	30	26	22	17					
Engines with 6 wheels coupled. Series :														
1.001 to 1.054 1.244 to 1.267 1.309 to 1.326	58	55	48	41	34	28	22	17						
1.101 to 1.150 1.224 to 1.243 1.268 to 1.308 1.327 to 1.364 1.397 to 1.400	60	59	56	50	44	39	34	28						
1.201 to 1.223	33	32	28	24	20	15	10	6						
1.401 to 2.000 2.403 to 2.409	86	84	76	68	60	52	44							
2.201 to 2.300	60	49	39	31										
2.390 to 2.400	109	93	76	64	53									
Engines with 8 wheels coupled. Series :														
2.501 to 2.530	180	150	119	94	69									

392. *Load of engines on fictive inclines zero that is to say on a horizontal and straight line.* The following table, relating for example to the direction *Modane* to *Saint-Michel*, applies identically as we have seen (387) to all the sections with the fictive incline zero one of the directions run in.

It is thus of course reproduced a great number of times in the book, and it expresses nothing else than the loads taken on a horizontal and straight line.

SECTIONS AND DIRECTIONS FOR WHICH THE FICTIVE GRADIENTS ARE ZERO, OR LOADS DRAWN ON THE HORIZONTAL AND STRAIGHT LINE.

Loads in tons which the engines of the divers types can draw at different speeds.

SPEEDS IN MILES :	10	13	16	19	22	25	28	31	34	37	40	43	47	50
Uncoupled engines. Series :														
1 to 40 51 to 76 161 to 170	480	417	370	332	293	261	235	213	194	176	153	131	113	97
Engines with 4 wheels coupled. Series :														
201 to 230	875	770	685	605	515	435	372	312	267	230	196	176	145	125
101 to 145 286 to 337 351 to 383 522 to 563 586 to 618 841 to 850	685	605	535	462	392	329	281	240	216	173	149	428		
451 to 468	825	715	605	505	414	346	291	247						
506 to 521	645	565	485	410	339	279	235	199						
146 to 160 396 to 400 564 to 585 631 to 645	640	561	500	450	393	341	291	256	225	195				
619 to 630 701 to 840 951 to 982 997 to 1.000	830	730	654	582	495	426	364	316	272	235				
Engines with 6 wheels coupled. Series :														
1.001 to 1.054 1.244 to 1.267 1.309 to 1.326	970	850	710	595	490	406	340	291						
1.101 to 1.150 1.224 to 1.243 1.268 to 1.308 1.327 to 1.364 1.397 to 1.400	1.035	910	805	700	595	500	428	367						
1.201 to 1.223	685	605	515	442	363	300	252							
1.401 to 2.000 2.403 to 2.409	1.235	1.130	965	815	675									
2.201 to 2.300	780	605	473	378										
2.390 to 2.400	1.280	1.020	795	640	510									
Engines with 8 wheels coupled. Serie :														
2.501 to 2.530	2.330	1.845	1.425	1.132	865									

393. To the preceding details, we shall add the following extract from the service order, which serves as preamble to the books of the load-tables.

. . . .

"Art. 3. On the same section the gradient is variable. In order to keep the work nearly constant for the engines, we have admitted that the speed of the trains should vary with the gradient; it ought to be higher, on flat gradients, than the mean velocity of the train, lower on the contrary, on the steep gradients. The velocity of the train can also be increased before taking a steep gradient, diminishing it gradually on the incline, in order to profit by the inertia on the ascent.

"We have thus been able, by supposing the use of these two means, to diminish appreciably the influence of steep gradients on the load-limits.

"On the other hand we have had to take into account the curves, and other circumstances unfavourable to the section.

"We have, definitively, taking these divers elements into account, assimilated each section to a fictive section of uniform inclination on a straight line; the influence of the inclines upon the loads varying with the speed, we have fixed, for each section, different fictive gradients for the trains of different speeds; these fictive gradients are inserted in the load-book which is mentioned farther on, at the head of the special table for each section.

"Sometimes in the interval of a section of ordinary change of engines, the differences of the gradients are too considerable to permit a constant and complete load for the engines, without exaggerating the differences of speed; in this case we have divided the changing section into several load sections. There results without doubt from this, a greater division of the trains; but this division can always be dispensed with if need be, and the train made up with a constant tonnage for a changing run, including several load-sections; the load must then correspond with the most difficult section. The train can of course, on each load-section, be run at different mean speeds, which allows by diminishing the speed on the most difficult sections, the constant load of the train to be increased.

"Art. 4. We have said that the speed of a train, on a running section, should be variable with the difficulty of the line.

"The mean velocity of a train is obtained by dividing the distance run (in miles), by the time (in hours) of the journey, from which has been previously deduced:

"1. At each departure for getting up speed:

"For ordinary trains, one minute;

"For express and goods trains, two minutes;

"2. At each stoppage for slackening, one minute;

"3. At every station the train has to stop at, the time fixed for the stoppage;

"4. For every time the speed is slackened without stopping, one minute.

"The printed time-bills of the trains ought to indicate for each train, per changing or load section, the mean speed of the train calculated in the above manner.

"On the sections with variable gradients, the times of the trains passing into the stations will be fixed so as to take into account the variations necessary for taking the maximum load, at a mean speed chosen.

"Tables prepared by the locomotive superintendent will fix:

"1. The list of the load sections on which, the section of the line being considered as uniform, the speed of the trains should be constant over the whole section;

"2. For each load section of variable gradients and speed, the partial velocities to be given to the trains for the different portions of the section, for mean speeds by 3 and 3 miles, from 9 up to 50 miles an hour.

"Art. 5. Atmospheric conditions may modify appreciably the power of the engines; the state of the rails modifies the adhesion; cold and wind increase the resistance, and may diminish the power of production of the steam, by increasing the losses. The loads indicated in the book all refer to a good state of rails, in a good season; we shall see farther on (arts. 10, 11 and 12) how unfavourable atmospheric conditions will be dealt with.

"Art. 6. The load of a train is expressed in tons, and represents the approximate weight of the vehicles and the useful load. Special instructions for the Traffic and Locomotive departments, will fix the rules to be followed for determining the gross load of each train.

"Art. 7. Books issued by the Locomotive department, one for each section of traction, will fix the load in tons that may be taken on each load section, for each type of engine, and for all speeds, increasing by 3 and 3 miles, from 9 to 50 miles an hour." (This is the book from which Nos 390, 391 and 392 give extracts).

"A double page of the book is devoted to each load section; this page is divided into two tables, one for the loads of the even trains, the other for the loads of the odd trains of the same section.

. . . .

"The loads are fixed in the books according to the power of the engines, but it is understood that these loads shall be reduced in the composition of the trains, as far as may be necessary, in order that the number of waggons composing these trains may not be superior to the figures fixed by the regulations.

"Art. 8. The locomotive department should inform the Traffic department at suitable times of the loads which the engines of the trains can take.

"To this effect, at each change of service in the regular trains, and at each service order issued for the regulations of extra trains, the district locomotive superintendents address to the head of the station (forming of trains), the description of the type of engine which will be supplied by their depôt for each regular train, or additional train.

. . . .

"Art. 9. The stations are specially informed for each train of the load which the engine can draw; to this effect:

"Every driver leaving the depôt to run a train or to take ballast-waggons, or to make a special journey, receives from his foreman an order for coupling on which bears:

"The official date and the number of the train; the names of the driver and fireman; the numbers of the engine and tender; *the load normal or reduced the engine is to take.*

"This order for coupling on is handed by the driver to the official of the traffic department in charge of the service to be done.

"Art. 10. We have said that the loads entered in the books correspond to good weather, and a good state of rails.

"There may be made, in these loads :

"1. Permanent reductions for a season, by the engineer in-chief, on the proposition of the local engineer of the section;

"2. Temporary and exceptional reductions by the heads of the depôts.

"The permanent reductions ought only to be applied in extreme cases, when it is fully established that the conditions of the atmosphere will not allow the normal loads to be drawn.

"These reductions are effected at the same time on all the loads of the section and by fractions of 0,05, 0,10, 0,15, or 0,20 of these loads; they never exceed 0,20.

"The locomotive superintendent proposes these reductions to the engineer-in-chief, who approves if there is ground, and advises the traffic department thereof. The advice indicates :

"1. The period at which the reduction should commence;

"2. The sections to which it is to apply;

"3. The amount of reduction.

"When circumstances warrant the suppression or the modification of the reduction, a new advice is sent to the traffic department by the locomotive superintendent.

"Art. 11. When, from any cause whatever, exceptional or unforeseen, such as snow, hoar frost, storm, etc., the head of a depôt thinks proper, for a train to be made up on a neighbouring section, that the normal load, or already permanently reduced, ought to undergo an exceptional reduction, he gives immediate advice thereof to the head of the station (formation of trains). This advice ought to indicate :

"1. The normal date and the number of the train to be reduced;

"2. The coefficient of the exceptional reduction;

"3. The motive of the reduction.

"The coefficients of exceptional reduction increase by fractions of 0,05, 0,10, 0,15, 0,20 of these loads, without other limit than that of the authority of the head of the depôt.

"The exceptional reduction includes, for the train in question, the permanent reduction, which it annuls and replaces.

"Art. 12. When from an unforeseen cause, the necessity for a reduction of load arises at a point of the section where there is no depôt, the driver may require from the head of a station or the chief of the train, the reduction of the load he is drawing. The requisition of the driver is entered on the way-bill and transmitted in the regular way to the locomotive superintendent who verifies it.

"Art. 13. When the necessity of an extra-load arises at an intermediate station where there is no depôt, the station-master may require the driver to accept such extra load.

"In any case the driver may accept or refuse the extra load, according to circumstances with regard to the state of the weather, of the nature or composition of the train, and of the state of the engine.

"If it is a question of a passenger-train, as the traffic department is bound to convey all who present themselves, the driver ought to accept the extra load, if circumstances permit him to insure the regular running of the train without fail, only with delay. In this case the requisition of the station-master relieves the driver from all responsibility of the consequence of the delay.

"If it is a question of a goods train, the driver ought not to accept the extra-load unless the circumstances permit him to guarantee the regular running of the train without break-down and without delays.

"The requisition of the station-master is entered by him on the traction note with the observations of the driver and his reservations as to delays; these observations and reservations with remarks by the chief of the depôt and the deputy locomotive superintendent are verified by the locomotive superintendent.

"Art. 14. The reductions, permanent or exceptional ought not to be asked for, excepting in cases of real necessity.

"The men of the locomotive department ought to strive constantly to obtain, at the same time as regularity in running, the utmost possible utilisation of the power of the engines."

. . . .

WEIGHT TO RECKON FOR THE VEHICLES IN THE LOAD OF THE TRAIN

. . . .

. . . « The weights to reckon in the tonnage of the trains for empty vehicles and cold engines of « the different types are the following :

« *Vehicles at high speed, empty :*

« Carriages, luggage-vans, and travelling post-offices with three axles.................. 8 tons
« Carriages, luggage-vans, and travelling post-offices with two axles.................. 7 »
« Brakes. — Horse tones. — Trucks.. 5 »
« *Vehicles at low speed, empty :*
« Low sided and platform waggons, trucks, closed waggons, cattle waggons, etc....... 5 »

« *Engines cold, and tenders :*

« A cold engine and its tender of whatever type :
« Without water or fuel... 50 »
« Full of water and fuel.. 60 »
« Engine alone, empty.. 35 »
« Tender alone, empty.. 15 »
« The weights to be reckoned in the useful tonnage of the vehicles are the following :

« *Vehicles at high speed* (when they are not running empty) :

« Passenger carriages (mean weight).. 2 »
« Lugagge-vans, and waggons loaded with parcels or with cattle (mean weight)...... 4 »
« Brakes, horse-boxes and carriage-trucks (mean weight)........................... 3 »
« Post office vans (mean weight).. 5 »

« *Vehicles at low speed :*

« The useful tonnage of low speed vehicles, that is to say the weight of the goods car- « ried, is taken from the loading sheets; it is counted in tons, neglecting for each vehicle « the fractions of a ton.

« By exception, the useful tonnage of the vehicles carrying cattle, whatever may be the « load, is taken at.. 4 »

« There generally results from the suppression of the fractions, a mean loss of 10 cwt « per waggon; this loss is compensated for by an increase of 10 cwt on the weight of the « empty waggons.

« The gross tonnage is obtained by adding together the weights of the vehicles and the « useful tonnage.

. . . .

« Waggons set apart for the service of the general stores, empty or loaded........... 7 »

394. *The Midi lines.* — The method followed on the *Midi*, includes two distinct operations:

1. The calculation of the tables by double entry, giving for each series of engines the loads they can carry at increasing speeds, and on increasing inclines;

2. The application of these tables to the *load-sections* into which the system of lines has been divided, the load relating to each of them being determined according to the gradient, the length and the position of the inclines (upwards).

1. *Formation of the tables.* — There is determined for each series of engines:

1° The adhesion, by application of the coefficient 0,13 to the adherent weight.

2° The function $\frac{pd^2l}{D}$, by applying to the pressure corresponding to the stamp, the coefficient 0,65; the maximum effort of traction T, which the engine can exert, is the smaller of these two numbers.

	SERIES of the engines.	WEIGHT of the engine with full tender. P.	VALUE of $0{,}65\frac{pd^2l}{D}$.	ADHESION $0{,}14$ P'.	T $\left(0{,}65\frac{pd^2l}{D};\right.$ or fP').
		tons.	tons.	tons.	tons.
Uncoupled..........	1 to 32	48,000	2,210	1,716	1,716
	33 to 40	48,000	2,210	2,100	2,100
Six wheels coupled...	(tank) 101 to 148	36,000	2,668	3,554	2,668
	148 to 189	50,000	2,668	3,003	2,668
	201 to 240	50,000	2,668	2,860	2,668
	302 to 345	56,000	5,331	4,810	4,810
	501 to 515	52,000	3,639	4,160	3,639
	601 to 640	56,000	5,438	4,689	4,689
	701 to 760	74,000	6,714	5,720	5,720
	801 to 888	55,000	4,418	4,511	4,418
	1011 to 1014	47,000	3,817	3,757	3,757
	1017 to 1019	»	4,298	4,875	4,298
Eight wheels coupled.	701 to 715	70,600	6,714	6,160	6,160

According to the empirical formula of *W. Harding* (III, 311), the resistance of a train (engine included) of the gross weight Π tons, at the velocity v miles

an hour, offering a reduced surface to the wind of 54 square feet, upon an incline (up) $\frac{1}{i}$, is

$$\left(6 + 0{,}33v + \frac{0{,}1367v^2}{\Pi} + \frac{1}{i}\right)\Pi,$$

a formula to which we shall return later on, and the exactness of which is considered as sufficient, on the Midi.

The weight of a train which an engine of weight P, capable of exerting at the velocity v an effort of traction T, can draw at that same velocity, and up an incline $\frac{1}{i}$, is then, because of $\Pi = \dfrac{T - 0{,}1367\,v^2}{6 + 0{,}33\,v + \frac{1}{i}}$:

$$\Pi - P = \frac{T - 0{,}1367v^2}{6 + 0{,}33v + \frac{1}{i}} - P; \quad \ldots\ldots\ldots \quad (a)$$

The effort of traction T, which the engine can develop is lower than the two limits: $T' = 0{,}14P'$; $T'' = \dfrac{0{,}65\,p\,d^2\,l}{D}$, independent of the velocity.

The smallest of these two numbers is the effort of traction which the engine can really exert, but only up to a certain limit of velocity, beyond which the effort ought to be reduced in consequence.

In order that the engine may keep up, at the velocity v, the effort of traction which its adhesion, the volume of its cylinders and its pressure warrant, its heating surface must be sufficient. These surfaces should be first of all brought into one common measure.

"We shall admit," says M. *Laurent*, chief locomotive engineer, in a note he has been good enough to communicate to me, "what results from experiments:

"1. That beyond 13 ft, 12 in length, the tubes adding nothing to the production of steam, it is sufficient to consider the heating surface on the supposition that the tubes are reduced to 13 ft, 12 long.

"2. That a square foot of indirect heating surface, producing an effect three times less than a square foot of direct heating surface, we can, from the point of view of comparison, estimate as direct heating surface by taking one-third of it.

"Let us take:

"S′ the heating surface of the fire-box;

"S″ that of the tubes supposed reduced to 13 ft, 12 in length.

"The heating surface which we shall call comparative will be:

$$S = S' + \frac{1}{3}S''.$$

TYPE of engines.		TUBES. Number.	TUBES. Length.	HEATING SURFACE. Fire-box.	HEATING SURFACE. Tubes.	HEATING SURFACE. Total.	Heating surface of tubes supposed reduced to length of 13 ft, 12.	Heating surface of tubes reduced and expressed in direct surface at 1/3.	Total comparative heating surface S	Available effort of traction T	$\frac{T}{S}$	Observations.
			ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	lbs.	lbs.	
Passengers	1	180	11,34	81,05	968,72	1049,77	968,72	322,91	403,96	3.783	9,04	
Mixed	149	180	14,62	81,05	1248,24	1329,29	1119,48	373,16	454,01	5.882	13,00	
Mixed	201	177	13,45	79,65	1104,41	1184,06	1088,11	362,03	441.68	5.882	13,03	
6 wheels coupled..	501	197	14,20	86,37	1329,10	1415,47	1217,81	409,26	495,65	8.023	16,02	
Dito	601	197	13,93	86,80	1273,18	1359,98	1199,13	399,71	486,50	10.318	21,04	
Dito	801	223	14,62	95,36	1477,38	1572,74	1324,95	441,52	531,53	9.740	18,03	(1)
Dito	801									9.945	18,07	(2)
Engerth	302	197	15,58	102,35	1518,95	1621,20	1279,10	426,36	528,71	10.604	20,00	
8 wheels coupled..	701	249	17,06	116,45	1970,37	2086,82	1523,16	504,23	615,14	13.580	22,01	

(1) With high speed wheels. (2) With low speed wheels. (325)

"The different engines can therefore develop per square foot of comparative heating surface, the efforts $\frac{T}{S}$ inserted in the last column of the table.

"If, without taking into account differences in the distribution, we admit *that the quantities of steam expended in a given time are sensibly proportional to the efforts of traction developed in the same time;*

"If we admit further, *that the passenger engine* (type 1), *running at* 37 *miles an hour is under suitable conditions of evaporation, which seems to result from the working of these engines*, there results therefrom that the mixed engine (type 149) for example, can only utilise its maximum effort, at a less velocity, such that the production of steam in that engine may be under the same condition as that of the passenger engine.

"This velocity is equal to 26,6 (*) miles an hour, or say in round numbers, about 25 miles an hour.

"A similar calculation brings out in the following figures the speeds which must not be exceeded so as to utilise the whole power of the engines:

TYPE OF ENGINES.		SPEED.	OBSERVATIONS.
		Miles an hour.	
Passenger		37	
Mixed	149	27	
Ditto	201	26	
Six wheels coupled	301	17	
Ditto	501	21	
Ditto	601	15	
Eight wheels coupled	701	17	
Six wheels coupled	801	19	With wheels of 5 feet.
Ditto	801	18	With wheels of 4,25 feet.

(*) This value explains the preceding enunciation, the clearness of which is not what it might be. It is admitted simply that the limits of the speeds are inversely as the efforts $\frac{T}{S}$.

" As long as these engines do not exceed the above speeds, the formula (a) can therefore be made use of to calculate the train loads.

" If an engine has to run exceptionally, at a higher speed than that fixed by its maximum effort, the effort which it is capable of exerting ought evidently to be reduced so as to be in accordance with the possible evaporation.

" Thus, to take again the example of the mixed engine, let us suppose that it is required to run at 37 miles an hour; we can only require from it an effort of 92 lbs per square foot of comparative heating surface, or a total effort of 4.184 lbs., very little higher than that of the passenger engine, and certainly compensated for by the excess of the resistance of the engine itself, due to the increase in the speed.

" A mixed engine with the same heating surface, but with wheels 6 ft, 89 in diameter (the same as the passenger engines), would utilise its maximum of power up to 35 miles an hour.

" It is by taking into account all the considerations which we have just enunciated, that the following tables have been calculated, giving for the principal types of our engines, the loads (not including the motor) drawn at different speeds up gradients of different inclinations.

I° PASSENGER ENGINES. — Adherent weight : 13,20 tons. Driving wheels of 6,8 feet.

GRADIENT ONE	NUMBER OF TONS DRAWN AT THE SPEED OF						
	25 miles.	28 miles.	31 miles.	34 miles.	37 miles.	40 miles.	43 miles.
0	229	209	185	168	156	125	94
1000	192	167	157	144	136	108	80
500	163	152	136	125	118	94	69
333	141	132	118	109	95	82	60
250	123	118	102	93	83	74	53
200	108	103	90	83	74	59	45
167	96	90	80	74	65	50	39
143	85	80	70	64	58	43	34
125	76	71	63	58	51	37	29
111	68	63	55	50	45	32	
100	61	56	49	44	40		
83	50	44	38	32			
71	40	36	29				
62	32	27	23				
55	26	21					
50	22	16					

II° MIXED ENGINES.

Series 149 to 180. — Heating surface : 1329 sq. ft. Adher. weight : 23 tns, 01. Driv. wheels : 5 ft, 67,
Series 201 to 240. — Dito. 1184 sq. ft. Dito. 20 tons. Dito. dito.

GRADIENTS one in.	NUMERO OF TONS DRAWN SPEED OF									
	16 miles.	19 miles.	22 miles.	25 miles.	28 miles.		31 miles.		34 miles.	
0	476	431	388	354	302	294	244	237	201	195
1000	390	358	327	300	259	251	210	203	173	168
500	327	303	279	259	225	217	182	177	150	146
333	280	262	242	226	197	191	160	150	132	128
250	244	228	213	201	175	169	142	137	117	113
200	214	203	191	180	156	150	127	122	104	105
167	191	181	169	160	140	135	114	109	93	90
143	171	160	154	146	126	122	102	98	83	81
125	154	147	138	132	115	110	92	88	74	72
111	137	132	126	120	105	100	84	80	67	65
100	122	118	114	109	95	92	76	73	61	59
80	106	102	98	94	80	77	63	60	50	48
71	89	86	81	78	68	65	53	50		
62	76	73	70	67	57	55				
56	65	62	59	57						
50	56	53	51							

Note. In the columns of the speeds of 28, 31 and 34 miles, the numbers in small figures refer to the engines of the series 149-180.

III° ENGINES WITH SIX WHEELS COUPLED.

Series 601 to 640. — Heating surface : 1360 sq. ft. Adher. weight : 38 tons. Driv. wheels : 4,26 ft

GRADIENTS one in.	NUMBER OF TONS DRAWN SPEED OF					
	12 miles.	15 miles.	19 miles.	22 miles.	25 miles.	28 miles.
250	488	460	370	287	227	185
200	431	408	334	274	202	165
167	382	366	296	230	182	148
143	347	331	268	208	164	133
125	315	302	244	189	149	120
111	288	277	223	173	136	109
100	264	254	205	158	124	100
83	225	218	175	134	104	83
71	195	189	151	115	89	70
65	171	166	132	100	76	59
56	151	146	116	87	65	50
50	134	130	102	76	56	42
45	119	117	91	66	48	35
42	107	105	81	58	41	29
38	96	94	72	51	35	24
36	87	85	64	45	30	
33	79	76	58	39		
31	72	70	52	34		
29	65	64	46			

ENGINE WITH EIGHT WHEELS COUPLED. — Diameter : 4,26 ft; heating surface : 2.186 sq. ft. Series 701 to 715, et 751 to 760. — Adherent weight : 44,000 tons.

GRADIENT ONE IN	NUMBER OF TONS DRAWN AT THE SPEED OF				
	12 miles.	15 miles.	19 miles.	22 miles.	27 miles.
250	591	556	466	358	275
200	527	494	414	318	246
167	465	442	376	286	215
143	422	400	336	258	200
125	380	363	311	234	182
111	348	334	279	214	166
100	317	305	257	196	152
83	270	261	219	166	128
71	233	226	189	142	114
65	206	197	164	122	93
56	179	174	144	106	79
50	158	154	127	92	68
45	141	137	112	80	58
42	126	123	99	70	50
38	112	110	88	61	42
36	101	98	79	53	35
33	91	89	70	46	39
31	82	80	62	39	24
29	73	72	55	34	19

"In order to carry into effect the application of these loads, the Midi system is divided on each line into load-sections in which the principal gradients, according to their position and their length, serve to determine the load to be drawn.

"To take an example, we shall determine the load to be fixed for an express train running at 37 miles, upon the portion of the line between *Bordeaux* and *Facture* (line from *Bordeaux* to *Irun*). The examination of the section of the line between these two points shows an up gradient of one in 200 on the first 7 miles (Pl. LXXXVI, *fig.* 7).

If this gradient has to be run up at 37 miles an hour, the load of the train should not exceed 9 carriages; but if we admit that it can be run over at a less speed, so that the time lost may be made up, as far as the speed of 43 miles an hour will admit of, on the down incline from the 14,88 to the 24,18 miles, and that the portion from the 6,84 to the 14,88 miles be run over at 37 miles an hour, the velocity V on the one in 200 will be :

$$6{,}8\,\frac{37{,}3}{V}+8{,}1\,\frac{37{,}3}{37{,}3}+9{,}3\,\frac{37{,}3}{43{,}5}=24{,}2\,\frac{37{,}3}{37{,}3}$$

whence $$V=\frac{248{,}8}{81}=31{,}1.$$

"Now at this velocity of 31 miles an hour, the load is 12 carriages.

"This load is consequently that which it is expedient to fix for the journey from *Bordeaux* to *Facture*.

"Considerations of this nature applied to each load section, have guided us in the determination of train-loads corresponding to each of these sections, for the service of passenger-trains as well as for goods.

"The loads which we have established according to the preceding tables, have been in perfect accord with the results of practice."

Without discussing this method in detail, which would lead us too far, we shall only remark: 1. that the quantities of steam expended in the unit of time, are sensibly proportional, not to the " efforts of traction," but to the quantities of work done; 2. that if the grounds which led to looking on the passenger engine running at 37 miles an hour as a sort of type of the normal conditions of evaporation, are correct, they are certainly anything but evident. It is difficult, in effect, to understand how, everything else equal except the velocity, any other engine should not be, simply by a suitable diameter of the driving wheels, placed under conditions of evaporation not only as favourable, but even entirely identical.

Moreover, a supplementary note of the 6th of December 1872 defines in a more explicit manner than the preceding, the mode of estimating the third limit T‴ of the effort of traction, that which results from the correlative values of the heating surface and of the speed:

"In order to calculate it", says M. *Laurent*, engineer-in-chief, we apply the following formula:

$$T''' = 374 \frac{S}{V},$$

which comes out of the observations which we have made.

"After numerous observations, we have been led to conclude that an engine can develop, up to the limit of 37 miles an hour, a tractive effort of 4.078 lbs, 5, when the heating surface (reduced) is 403,5 square feet.

"Starting from these results, and admitting that the effort of traction per square foot of heating surface is inversely proportional to the velocity, we obtain the relation:

$$\frac{T'''}{S} : \frac{4.078,5}{403,5} :: 37 : V,$$

which furnishes the formula given above

$$T''' = 374 \frac{S}{V}.$$

"Let us take for example, an engine of series 701 with eight wheels coupled, in which $P' = 440$ tons and $S = 614,8$ square feet, and let us find its effort of traction corresponding to each of the velocities of 12 and 18 miles an hour.

On the supposition of 12,4 miles an hour, we shall have:

$$T' = 0,14 \times 44 \text{ tons} = 6,16 \text{ tons},$$

For 18,

$$T'' = p \frac{d^2 l}{D} \quad . \quad . \quad = 6,71 \text{ tons},$$

$$T''' = \frac{S}{V} \times 374 \quad . \quad . \quad = 8,46 \text{ tons}.$$

"In this case, $T = 6,16$ being the least of the three expressions of T, it is that which we take to replace T in the formula (a).

" In the hypothesis of 18 miles an hour, we shall have:

$$T' = 6{,}16 \text{ tons},$$
$$T'' = 6{,}71 \quad »$$
$$T''' = 5{,}64 \quad ».$$

" In this case, it is $T''' = 5$ tns, 64 the least number, which we adopt for the value of T."

The inverse proportionality between the effort of traction and the speed is not admissible for the same engine running at different speeds. This proportionality is nothing else than the constancy of the available work on the driving-wheels; now, with an equal production of steam, this work increases with the speed, the admission diminishing, and the expansion consequently increasing. We shall return to this point when we examine, on the subject of steep gradients, the mode of determining the loads followed on the Upper Italy system of lines (413).

What is particularly striking, if we compare the loads on the *Midi* with those of the *Méditerranée*, is, as indeed might be expected after what precedes (386), the inferiority of the first for engines at a very slow normal speed. The eight-wheeled engines, for example, have very nearly the same heating surface, 2.152 square feet, and, consequently the same power. Now their loads are:

At the speed of....................		Miles an hour 12	15	19	22	25
		tons	tons	tons	tons	tons
1. up one in 250	Méditerranée.	853	675	555	443	»
	Midi.........	591	556	466	358	275
2. up one in 33	Méditerranée.	130	101	79	57	»
	Midi.........	91	89	70	46	39

The discrepancy is very considerable. It might be attributed, partly, to the less weight, and consequently smaller adhesion of the Midi engines (259); but in spite of their relative lightness, they do not want adhesion at a speed of 12 miles an hour under the climate of the South of France. The discrepancy in question results therefore from the very unequal utilisation of the boilers at the practical velocities (386, 387), and of the different modes adopted for estimating the influence of the speed on the load.

395. *Orleans system.* — On the *Orleans* lines, the loads have been revised and fixed by a regulation in force since 1870. The different sections have been divised into *sub-sections*, and these sub-sections have been

united in groups in the load-book, according to the conditions of their trace: gradients and curves. To each of these groups a page of the book refers, indicating for each series of engines, the load it can draw at the different speeds.

It is clear that the same *sub-section* figures in general on two tables: on the one for the direction run in, on the other for the other direction. The book contains two series of tables, one for passenger and mixed trains, the other for goods trains. The gradients inserted in the tables are the mean gradients, and without doubt indeed the mean gradients more or less reduced in virtue of similar considerations to those which served to determine methodically, the fictive inclines of the *Méditerranée*.

We reproduce:

1. Two tables containing a numerous group of *sub-sections* under mean conditions of trace, and relative, the one to mixed trains of passengers, the other to goods trains;

2. The two tables which refer to the most difficult section, both as regards plan and section, that of the crossing of the Lioran.

If these indications suffice to make the working of the process adopted on the *Orléans* lines understood, there is one main point, the real starting point, left in the shade: the normal evaporation of the different types of engines at the various speeds. The comparison between the different systems of lines, of the heating surface and the loads drawn at the same speeds on the same inclines, would lead to consequences analogous to that indicated farther back (394) and to insist further thereon, would be taking up too much space with a subject which in spite of its importance, is really a digression.

PASSENGERS AND MIXED. — N° 8. — **One in 100.** — **Curves of 875 yards.**

Subdivision of section.		Argenton to.... Éguzon. Limoges to..... Ambazac. Poitiers to..... Montmorillon. Saint-Sulpice to Montmorillon.		Bressuire to. Niort. Périgueux to Limoges. Périgueux to Agen and back. Penne to.... Villeneuve-s.-L. do.		Tulle to....... Brive. Capdenac to.... Viviez. Lexos to...... Villeneuve. Capdenac to.... Villeneuve.		Figeac to..... Maurs. Commentry to. la Presle. (*) Murat to...... Arvant. (*) Vic-sur-Cère to la Capelle-Viescamp. (*)					
NATURE of the trains.	Speed in miles	18,6		21,7		25,0		28,0		31,0		34,2		OBSERVATIONS.
	DESIGNATION of the series of the engines.	Normal loads. ton.		Normal loads. ton.		Normal loads. ton.		Normal loads. ton.		Normal loads. ton.		Normal loads. ton.		
		For 1 engine.	For 2 engines.	For 1 engine.	For 2 engines.	For 1 engine.	For 2 engines.	For 1 engine.	For 2 engines.	For 1 engine.	For 2 engines.	For 1 engine.	For 2 engines.	
Mixed......	10 to 35	8	13	8	13	7	11	7	11	6	10	6	10	(*) Although the subdivision from Commentry to la Presle, Murat to Arvant, and Vic-sur-Cère to la Capelle-Viescamp are classed in up gradients of one in 100 for the composition of the trains, the number of brakes regulated by General order No 12, on these subdivision of one in 65 and one in 56 down is none the less in force.
	250 to 262	9	14	9	14	8	13	8	13	7	11	6	10	
	66 to 98	11	18	10	16	10	16	9	14	8	13	7	11	
	263 to 294	11	18	11	18	11	18	10	16	9	14	8	13	
	99 to 124, 314 to 338, 345 to 359	12	19	11	18	11	18	10	16	9	14	8	13	
	339 to 344, 592 to 600	13	21	12	19	11	18	10	16	9	14	»	»	
	236 to 250	12	19	12	19	12	19	11	18	10	16	9	14	
	129 to 170, 361 to 380	15	23	13	21	12	19	11	18	10	16	9	14	
	401 to 447	16	24	14	22	13	21	12	19	11	18	10	16	
	381 to 385, 510 to 515	17	24	16	24	14	22	13	21	12	19	»	»	
	173 to 224, 386 to 393, 566 to 591	18	24	17	24	15	23	14	22	13	21	12	19	
	516 to 565	21	24	19	24	17	24	16	24	15	23	»	»	
	Speed in miles	25,0		28,0		31,0		34,2		3,73		40,4		
Passengers.	10 to 35	8	13	8	13	7	11	6	10	5	8	»	»	
	251 to 262	10	16	9	14	8	13	7	11	6	10	»	»	
	66 to 98	12	19	11	18	10	16	9	14	»	»	»	»	
	99 to 124, 263 to 294, 314 to 359, 592 to 600	13	21	12	19	11	18	1	16	8	13	»	»	
	129 to 170, 236 to 250, 361 to 380	15	23	13	21	12	19	11	18	10	16	»	»	
	401 to 447	16	24	15	23	14	22	12	19	»	»	»	»	
	381 to 385, 510 to 515	18	24	16	24	15	23	»	»	»	»	»	»	
	173 to 224, 386 to 393, 556 to 591	20	24	18	24	16	24	4	22	13	21	»	»	
	516 to 565	22	24	20	24	18	24	»	»	»	»	»	»	

PASSENGERS AND MIXED. — No 14. — **Gradients of one in 33. — Curves of 328 yards.**

DESIGNATION of the journeys.	NATURE of the trains.	SPEED		DESIGNATION of the series of engines.	NORMAL LOADS in tons.		OBSERVATIONS.
		inscribed.	up.		For 1 engine.	For 2 engines.	
Vic-sur-Cère to le Lioran. Murat to le Lioran........	Passenger (Mixed).	miles. 19	miles. 11	516 to 565 1101 to 1113 1114 to 1140	tons. 74 110 116	tons. » 165 170	Goods waggons must always be placed in front of mixed trains.
		22	13	516 to 565 1101 to 1113 1114 to 1140	64 105 110	» 152 156	
		22	16	516 to 565 1101 to 1113 1114 to 1140	56 95 100	» 135 140	The weight of goods waggons will be calculated according to their load and entered tare.
		28	19	516 to 565 1101 to 1113 1114 to 1140	48 75 85	» 110 120	Vans and passenger carriages will be reckoned at 8 tons gross.
	Passenger....	28	19	516 to 565	48	»	or six carriages including the vans.

1. The limit of load, for the resistance of the couplings, is: 150 tons for mixed passenger trains with one engine; 115 tons for passenger trains with one engine.

2. The load of trains with two engines is calculated by supposing one engine 516 to 565, coupled to an engine of 1.101 to 1.140, conformably to instructions : 3.091 of 21st june 1859.

GOODS. — N° 8. — **Gradients one in 100. — Curves of 875 yards.**

Subdivisions of section.				
	Argenton to.... Éguzon. Limoges to.... Ambazac. Poitiers to.... Montmorillon. Saint-Sulpice to Montmorillon. Bressuire to... Niort.	Périgueux to. Limoges. Périgueux to. Brive and back. Périgueux to. Agen do. Penne to.... Villeneuve-s.-L.,do. Tulle to..... Brive.	Capdenac to.... Viviez. Lexos to........ Villeneuve. Capdenac to.... Villeneuve. Figeac to....... Maurs.	Commentry to. la Presle. Murat to....... Arvant. Vic-sur-Cère to. la Capelle-Viescamp. (*)

NATURE of the trains.	Speed of.... DESIGNATION of the series of engines.	9 miles. Normal loads. ton. for 1 engine.	12 miles. Normal loads. ton. for 1 engine.	12 miles. Normal loads. ton. for 2 engines.	16 miles. Normal loads. ton. for 1 engine.	16 miles. Normal loads. ton. for 2 engines.	19 miles. Normal loads. ton. for 1 engine.	19 miles. Normal loads. ton. for 2 engines.	OBSERVATIONS.
Goods and goods mixed.	333 to 359, 361 to 366, 592 to 600	From Capdenac to Viviez for 1001 to 1020	15	»	14	»	12	»	Although the subdivisions from Commentry to la Presle, from Murat to Arvant, and from Vic-sur-Cère to la Capelle Viescamp are classed in up gradients of one in 100 for the composition of the trains, the number of brakes regulated by general order No 12, on these subdivisions in down inclines of one in 65 and one in 56, is none the less in force. — Limit : 40 waggons.
	381 to 385		16	»	15	»	13	»	
	385 to 393		17	»	16	»	14	»	
	566 to 591 and 646 to 651		19	»	18	»	16	»	
	510 to 515		22	»	21	»	19	»	
	658 to 719	19 waggons loaded with 10 tons, of iron ore or coal.	23	37	22	36	20	33	
	601 and 720 to 791		25	40	24	39	22	36	
	516 to 565 and 792 to 811		28	40	26	40	24	39	
	812 to 891 and 983 to 994		30	40	28	40	26	40	
	1101 to 1113		36	40	34	40	»	»	
	1114 to 1140		38	40	36	40	»	»	
Cattle......	333 to 359, 361 to 366, 592 to 600	»	17	»	16	»	14	»	Same observations as above for subdivisions from Commentry to la Presle, from Murat to Servant, and from Vic-sur-Cère to la Capelle-Viescamp. Limit : 48 waggons.
	381 to 385	»	19	»	17	»	15	»	
	386 to 393	»	20	»	19	»	16	»	
	566 to 691 and 646 to 651	»	22	»	21	»	19	»	
	510 to 515	»	26	»	25	»	22	»	
	658 to 719	»	27	43	26	42	24	39	
	601 and 720 to 791	»	30	48	29	46	26	42	
	516 to 565 and 792 to 811	»	33	48	31	48	29	46	
	812 to 891 and 983 to 994	»	36	48	33	48	31	48	
	1101 to 1113	»	43	48	41	48	»	»	
	1114 to 1140	»	45	48	43	48	»	»	

GOODS. — No 14. — **Gradients one in 33. — Curves of 328 yards.**

Subdivisions of section. Vic-sur-Cère to le Lioran. Murat to le Lioran.

NATURE of the trains.	Speed of…… DESIGNATION of the series of engines.	11 miles. Normal loads. ton. for 1 engine.	11 miles. Normal loads. ton. for 2 engines.	9 miles. Normal loads. ton. for 1 engine.	9 miles. Normal loads. ton. for 2 engines.	7 miles. Normal loads. ton. for 1 engine.	7 miles. Normal loads. ton. for 2 engines.	OBSERVATIONS.
		tons.	tons.	tons.	tons.	tons.	tons.	
Goods and goods mixed.	516 to 565 and 792 to 811	86	»	82	»	74	»	The number of waggons will be calculated according to load and tare.
	812 to 891 and 983 to 994	92	»	88	»	80	»	
	1101 to 1110	120	180	115	175	110	465	
Cattle.	1114 to 1140	126	»	120	»	116	»	Cattle waggons will be reckoned at 9 tons gross.
	1201 to 1203	160	»	150	»	»	»	
								160 tons is the limit for two engines in front of the train.
								The load of trains with two engines is indicated for the two types 1101 and 516 to 565 up gradients of one in 33, according to instructions No 3103.

396. *Eastern of France.* — A more summary process has often been employed. The Eastern of France system, for example, has been divided, according to the gradients, into eleven section-types, between which the different lines have been distributed, divided into portions the more numerous, the stiffer they are:

« Section A line horizontal, or down gradients as high as one in 100, or short *up* gradients of from one in 333 to one in 250.
» B continuous up gradients, from one in 333 to short ones of one in 166.
» C mean up gradients of one in 200.
» D up gradients comprised between one in 166 and one in 143.
» E up gradients of one in 125 and one in 111.
» F up gradients of one in 100 and one in 91.
» G up gradients of one in 83 and one in 73.
» H up gradients of one in 73 and one in 59; mean one in 67.
» I up gradients of one in 62,5 to one in 55; mean one in 59.
» K up gradients of one in 55 to one in 50.
» L up gradients above one in 50 up to one in 38.

The same division is comprised for the two directions run in, sometimes, on the same section, sometimes, and oftener on two different profiles. To each profile correspond two relative columns, one for the even trains, the other for the odd ones. The lines from *Paris* to la *Ferté-sous-Jouarre;* from *Chaumont* to *Chalindrey;* from *Charleville* to *Tournes*, belong, for both directions, the first to the profile B, the two others to the profile C. *Reims* to *Guignicourt* belongs to the profile B, *Guignicourt* to *Reims* to the profile C; *Avricourt* to *Dieuze* to the profile C, *Dieuze* to *Avricourt* to the profile E, and so on.

This classification is convenient in practice. Experience often points out that the arrangement of the different section-types of a line ought to be modified; a service order of the 22nd October 1872, for example, changes the classification of the section-types (5 in number for the odd trains and 4 for the even trains) of the line 45 (*Troyes* to *Chaumont* by *Chatillon*). It is sufficient to inform the staff that a certain partial section-type passes from one letter to an other, and the matter is settled.

Those portions of the system with continuous down gradients above one in 100 (sections G to L on the ascent) do not figure in these section-type; they form a special group, under the name of: profiles with steep gradients.

The maximum load of the trains (Art. 37 of general order No 7) is limited to one and a half the maximum load, on the ascent, of the regular engine of the train, whatever number of engines may be put on to the head of the train; and the number of vehicles must not exceed :

60 for the lines classified for the ascent, to the sections G, H.
50 .... I, K.
40 .... L.

This without prejudice, of course, to the rules relative to the number of brake a point reserved, and which will be treated apart.

The table of the loads of the mixed and goods trains indicates for each section-type and for each type of engine, with reference to its power and its normal speed, the minimum and maximum of the load it ought to take.

These loads are expressed in units of 10 tons.

For the establishment of the number of units which a train represents, each empty vehicle is counted as 5 tons, or half a unit.

The minima loads should be taken in any weather.

The maxima loads should never be exceeded.

The load of the trains is thus always comprised between these minima and maxima, and is determined every day by the locomotive department.

The article 13 of the general order No 12 applicable only to the sections A up to F inclusive, and a circular already quoted (263) state:

" For trains drawn by two engines, the load ought not to exceed the sum of the minima loads fixed for each engine, reduced by 5 units whatever may be the state of the weather; it may even be taken at less, on account of the state of the couplings, if the head of the depôt requires it."

The general order No 7 (locomotive department) keeps up (art. 44) the rule indicated for the profiles A and F, and completes it as regards the section-types G to L, upon which the limit of the load is fixed at the sum of the minima loads for each engine, but always with the right of reduction allowed to the heads of dépôts, if they are afraid of the couplings.

The reduction of 5 units has then thus disappeared.

The order No 7 goes even farther when it is a question of an auxiliary engine on one of the up-gradients for which a special auxiliary service is organised.

" The load of the train may then (art. 42) be equal to the sum of the loads authorised for each of the two engines" (and no longer only to the sum of the minima).

The Eastern of France Company has thus introduced some modifications, a little timid, it is true, to the application of the principle laid down in such absolute terms in the circular of 1865 cited farther back (263) and in the

general order of 1866, that is to say of the notable inferiority of power of two engines attached to one train.

The numbers of the vehicles must not also exceed the following limits:

1. *Simple traction* (article 38).

Sections A to D : once and a half the minimum number of units.
Sections E to G : once and three quarters.
Sections H to L : twice.

2. *Double traction* (article 44).

Sections A to F : once and a half the minimum number of units stated for the load of the most powerful of the two engines.
Sections G to L : twice the number of units representing the minimum load of the regular engine of the train.

Besides, on the sections with *steep gradients*, that is to say above one in 100, the number of vehicles must not exceed the following limits (art. 38) whatever number of engines may be coupled on to the train :

60 vehicles, on the descent of the classified lines, on the ascent, on the sections G, H.
50 .... I, K.
40 .... L.

We shall conclude by the statement of the loads carried, on the divers sections, by the engines 0,501 to 0,600 (eight wheels coupled) at speeds comprised between 9 and 16 miles an hour:

A		B		C		D		E		F		G		H		I		K		L	
Minima.	Maxima.	Minima.	Maxima.	Minima.	Maxima.	Minima.	Maxima.	Minima.	Maxima.	Minima.	Maxima.	Minima.	Maxima.	Minima.	Maxima.	Minima.	Maxima.	Minima.	Maxima.	Minima.	Maxima.
tns	tns	tns	tns	tns	tns	tns	tns	tns	tns	tns	tns	tns	tns	tns	tns	tns	tns	tns	tns	tns	tns
560	720	500	640	460	570	420	520	360	460	300	400	270	370	230	330	180	250	160	210	130	180

397. *Ceinture railway* (*). — *Kœchlin's tank engines with eight wheels.* The limits of the loads taken on the Ceinture line, by the eight wheels coupled engines of *Kœchlin* (259) are fixed thus:

(*) This is the railway surrounding *Paris;* in the same way that the North London, East London, South London, and Brighton lines do London. (*Trans. note*).

	SPEED.	LOAD IN TONS.	
		Minimum.	Maximum.
	miles.	tons	tons
From *Batignolles* to *Aubervilliers* (3 miles, gradient of one in 143), no curves	9 to 12	270	360
From *Aubervilliers* to *Ivry* (6 miles, one in 99; curves of 547 yards	9 to 12	240	320

An engine of this type has been submitted to some methodical trials on the line from *Charleville* to *Hirson*.

M. *Dieudonné* shows in his notes that from *Tournes* to *Rimogne* (6,2 miles), the engine ascended one in 66,6, almost continuous, with a load of 261 tons, not without slipping a little (the experiment was made in the month of February). However, 5 miles of the incline were gone over without slipping at the speed of 10,56 miles an hour, with a mean effort on the coupling bar of 4 tns, 75. The pressure was easily kept up to the maximum of 117 lbs on the square inch. The admission was 56 per cent.

After a stoppage at the distant-signal at *Rimogne*, the starting had to be done on the incline, and the engine exerted an effort of 7 tns, 42.

To a traction of 4 tns, 75 on the coupling bar, corresponds, according to M. *Dieudonné*, a tangential reaction of the rails on the wheels of 5 tns, 90, or $\frac{1}{7,8}$ of the weight; " the indifferent state of the rail did not allow," says he, " of a greater effort of traction. But the production of steam was amply sufficient to keep up this running."

This estimate at 5 tns, 90 of the total tangential effort leaves $5,90 - 4,75 = 1,15$ tons for the total resistance of the engine. Gravity absorbs 45,74 (the weight at the middle of the trip) $\times \frac{1}{66,7} = 0,686$ of a ton; there thus remain 0,464 of a ton, or 26 lbs, 45 per ton, for the resistance, as a vehicle, of the engine with eight wheels coupled, at a speed from 9,32 to 12,43 miles an hour.

We shall return to this estimate. (III, 333.)

M. *Dieudonné* concludes thus:

" If we confine our conclusions to winter working, we should say that the tank-engine is very advantageous, as regards power, on lines with steep gradients, when the distance between the depôts of fuel, allows the supply to be reduced to 2 or 3 tons at the most. But the experiments should be repeated during the fine season."

The consideration of the distance between the fuel depots is secondary;

it is the distance between the water columns which is especially important; and when these are close enough together, the advantage of the tank engines is evident, as fully in winter as in summer.

398. *The Upper Italy lines.* — The method followed on this system of lines for the determination of the loads deserves to be noticed. But an example will suffice, and we shall choose by preference, that of the engines devoted to the working of the gradients of one in 33,3 of Mount Cenis. It will therefore come better in the chapter concerning steep gradients (413).

CHAPTER XII

UTILISATION OF THE WEIGHT OF FUEL AND WATER FOR INCREASING THE ADHESION OF THE ENGINE.

399. If the adhesion due to a fraction of the weight is sufficient for passenger engines, and the total adhesion for engines running at the ordinary speed of goods, it becomes evidently too small for a much less speed.

We have already said (379, 381, 382) that the speed may be fixed at 9 miles an hour, without the traction being disturbed by the tendency to slip; in general therefore, this limit is far enough from being reached. But if a speed notably less be adopted, 5 or 6 miles an hour, or less still, we must of course consider : whether to load the engine, or to seek for a supplement to the adhesion independent of its weight.

It is especially on steep gradients that a very low speed is induced the adoption of, in order to increase the available effort of traction, and to improve in that way, the very unfavourable ratio between the useful weight drawn and the weight of the motor. But it is precisely also on steep gradients that loading the engine must not be dreamed of. It is therefore wrongly that the application to the engine has been proposed, of a tank to be filled with water at the foot of the gradients, and emptied at the top, as a mean of running up steep gradients with a more reduced speed, and consequently with a greater useful load. Were however this expedient to attain the object, it would be inconvenient and costly to apply.

The systematic extra weight brought upon the engine, applicable at any rate only within very restricted limits, is not therefore admissible excepting on a line with flat gradients. By increasing the weight by p, the adhesion increases by fp and the effort of traction also, as long as the speed is low enough for the adhesion to fix its limit. The weight drawn increases itself then by the amount $\pi - p$, that is to say by $\dfrac{fp}{r+\frac{1}{i}} - p$; π being given by the relation $fp = \pi\left(r + \frac{1}{i}\right)$. For $\frac{1}{i} = 0$, that gives: $\left(\frac{f}{r} - 1\right)p$; if $f = \frac{1}{7}$, et $r = 0{,}004$, the weight drawn is increased by $34p$.

If the inclination is $\frac{1}{i} = f - r$, we have $\pi = p$, $\pi - p = 0$, and nothing is gained for the weight drawn. Beyond that, there would be a loss.

The engines with four wheels coupled, built by *Schwartzkopf* for the North-eastern of Switzerland, are provided with a tank which is filled with water, when the state of the rails threatens slipping. This contingent ballast, which can besides be made use of for supplying the boiler if the tender-water fails, is evidently much preferable to a permanent extra-weight. It has also been applied, but for correcting the distribution of the weight, by *Black* and *Hawthorn*, to the tank engines with six wheels coupled for mining purposes, mentioned farther back (332, 3rd); the supply of water is apportioned between a saddle tank over the boiler, and an ordinary tank behind. Nothing is taken from the latter until the first is emptied. The principal function of the tank behind is to correct the fault of engines with six wheels coupled and with the hind axle beyond the fire-box, that is to say the insufficiency of the load on that axle. It is a ballast, which carries the centre of gravity over towards that axle; and this ballast has two objects.

Tank engine. — On steep gradients, the only means always logical, but not always practicable, of weighting the engine, consists in making it carry what it must of necessity draw, that is to say its supply of fuel and water. Not only is the adhesion thus increased, but the dead weight is thereby reduced; the engine and tender united in one single vehicle being, everything else equal, of less weight than the two distinct vehicles, the more so as these always require a more considerable total number of axles.

But we have already seen (320) that if in principle the tank-engine is especially suitable for steep gradients, its application is subordinate to a condition which is not always fulfilled, that of the facility of establishing the water columns at very close intervals; a condition the more necessary, as the consumption per mile of the engine, very considerable in this case, on account of the low speed at the maximum of work, is too often increased by slipping, the effort of traction being very close to the limit of adhesion.

The suppression of the tender is thus a considerable advantage on steep gradients, which ought to be profited by when circumstances permit; but it must be looked at twice before *localising* engines too much, the supply of water for which would be insufficient on the portions of the line where the water columns might be fewer; although strictly speaking, they can be withdrawn from this specialisation, at need, by applying a separate tender to them.

400. *Engines with working tender.* — While giving up, on gradients, one of the advantages of the tank-engine : the decrease of the dead weight, it has been sought to keep the other : the adhesion due to the weight of the fuel and water. Hence, the engines with working tender. The tender is provided with cylinders, which receive the steam from the boiler through flexible pipes, an arrangement analogous to that which constitutes rightly or wrongly the principal objection against the *Seraing* engines, and those of *Fairlie* and *Meyer* (359 and following), and the disadvantages of which are indeed aggravated by the distance between the two vehicles. Thus there is no return of the steam from the tender to the smoke-box; it is lost for the draught.

The first application of the working tender was made by M. *Verpilleux* on the line with a gradient of one in 69, from *Rive-de-Gier* to *Saint-Étienne:* later Mr. *Sturrock* introduced it on the Great Northern. It is well to define the conditions and the special object of each of these applications.

For M. *Verpilleux*, it was not only adhesion which was wanted, but power itself; this want of power arose fortunately, not from the insufficience of the heating surface (in that case there would have been only one remedy: to lengthen the boiler, and particularly the fire-box), but from the insufficiency of the volume of the cylinders. Instead of replacing the cylinders by larger ones, which would only at any rate have remedied the second drawback, it was perfectly logical to apply small cylinders to the tender; a suitable relation was thus established between the heating surface and the total volume engendered by the pistons, and at the same time the adhesion was placed in the proper relation to the effort of traction. The operation was the better devised and the more necessary, as a complete alteration of the engine based on the lengthening of the boiler, and changing the cylinders was not interdicted only by the consideration of expense: on account of the weakness of the rails, the contractor for the haulage of the trains was limited to 13 tons for the engines, and this weight would have been notably exceeded.

It was thus a question, for M. *Verpilleux*, to correct in a simple and economical manner a fault in the proportions of his engines. Thus when they had done their time, they had to give way to others more powerful, when moreover the relaying of the road permitted, these engines in spite of their more considerable weight, to be placed on only six points of support, care was taken not to keep on the working tender, but to duly proportion the engine.

For Mr. *Sturrock*, it was an other question. On the English lines of great

traffic, the multiplicity of fast trains requires a speed to be given to the goods trains, which in themselves these latter do not require. The lines must be cleared; therein, by the way, consists one of the principal motives for the high speed at which the goods are run; on account of which honor is done in France to the liberality and to the good organisation of the service on the English lines. There is no great merit in doing what cannot be helped. On the Great Northern, coals travel at the rate of 20 miles an hour, stoppages included.

It is well to be able, at need, to force this speed occasionally, or what comes to the same thing, to avoid too much slackening on the inclines. A goods train, pressed closely by a passenger train, may thus rapidly get on to a lie-by and avoid delaying the passenger train by signals to slacken speed. On that account the evaporation must be pushed on very actively, and go beyond its normal figure; but the position of affairs is soon arrived at, in which M. *Verpilleux* was previously to the modification of his engines; that is to say in the presence both of adhesion insufficient to meet the increase of resistance resulting from the increase of speed, and of too small cylinders, the more so as it is a question of expending at each moment, not only the steam produced, but often more: to give in a word, a *spurt*.

It would not be sufficient to lengthen the admission, which at the same time is contrary to a good use of the steam. Without dwelling for the moment on this point, let us remark only, that a too prolonged admission, involves too great a back pressure, on account of the delayed opening of the exhaust.

With the auxiliary tender, a velocity can be given to the train higher than that for which the load has been estimated on a given section. The cylinders and the adhesion of the tender keep up (but during a very limited time, for the pressure is not long in lowering) the relation which ought to exist between the production of steam thus increased, and the elements of the engine.

The application of cylinders to the tender may, under such circumstances, be warranted; these cylinders act, then, only occasionally, during that outburst of the evaporation, and especially of the expenditure. But still their action would be frequently enough necessary to warrant the complication.

Later on, Mr. *Sturrock* wished to extend the principle. Instead of seeing in the working tender applied to a well proportioned engine, a simple expedient which allowed him to give a spurt, he wished to make a regular

type of the whole thing, for permanent application. Hence it was necessary to make the evaporation proportionate to the volume engendered by the four pistons, that is to say, to increase the heating surface. The engines had six wheels 5 ft,0 in diameter, and cylinders 1,34 by 2 feet. The tenders with six wheels coupled 4 ft,50 in diameter, received cylinders 1 foot by 1 ft,25. The fire-box was lengthened, the grate surface increased in the ratio of 8:13; and the adherent weight increased from 35 tons to 60.

Commencing in 1863, engines thus altered ran on the line from *Manchester to Sheffield*; and according to Mr. *Sturrock* the load drawn was increased by 50 per cent (45 waggons instead of 30). If this were so, the alteration in question was doubtless connected in one point with that of M. *Verpilleux's* engines, that is to say that it included the rectification of faulty proportions. With its 35 tons weight, the primitive engine had 5 tons adhesion; in order for it to develop an equal effort of traction measured on the pistons, a mean effective pressure 194

$$p = \frac{5 \times 2.240 \times 5{,}0 \times 12}{1{,}34^2 \times 12^2 \times 2 \times 12} = 105{,}25 \text{ lbs}$$

on the square inch; and to have the effort of 5 tons measured not on the pistons, but on the wheels, that is to say deducting the resistance of the machinery, it required on the pistons at least $\frac{1}{10}$ more, or nearly eight atmospheres: a pressure which certainly was not reached, especially at the high speeds of the goods trains on the Great Northern, and although the boilers were worked at 150 and 160 lbs on the inch, which, by the way, explains the frequent explosions on that line; that pressure in the boiler should have been raised to nearly 12,5 atmospheres, at least $(\frac{8}{0.65})$. The cylinders were thus too small.

It will be hardly admitted that an engine with a working tender, not merely for an occasion, but as a constant normal element, of the transmission of the work developed by the boiler, could, as regards economy of construction, maintenance and consumption, bear a comparison with a single engine of the same power, and having also the number of axles required by its weight.

What is, moreover, significative, is that Mr. *Sturrock* having left the Great Northern, the working tender should have disappeared with him. At the same time the undue pressures have been given up, which applied occasionally might warrant the type in question

401. *Circumstances which may warrant the principle of this engine.* — Let us return to this point of view, that the engine is so constituted as to dispose of a forced production of steam, and even to expend, during a space of time necessarily very short, more than it produces; it is clear that this property may be quite as well applied (and even with more reason, seeing that a greater supplement of adhesion may then become indispensable) for the increase of the tractive effort to be developed on a steep gradient, as for an increase of speed on a flat gradient. It was, in effect, by considerations of this nature that M. *Vuillemin*, the locomotive engineer of the Eastern of France, in a note presented to the jury of the Exhibition of 1867, founded the construction of an engine with working tender, delivered to that railway (Pl. LXIX and LXX) from the *Graffenstaden* shops. The adoption of this type may thus be justified by the conditions of the trace of the line; if it is very uneven, if it presents a series of short gradients, the faculty of forcing, at need, the production and particularly the expenditure of steam without being exposed to a want of adhesion, may receive its application; but if the inclines are long, the conditions of this production and of this expenditure ought to be constant thereon, under penalty of stoppages, and impossibility of starting. The normal proportion between the elements, — heating surface and volume of cylinders, — ought to be established *for all the four cylinders together*, and hence that would cease to be so, if those of the tender were not acting.

The working tender may however, even then, have grounds for its adoption, in one case : that where a normal velocity might be adopted, lower than that for which the adhesion of the engine alone would be sufficient. The excess, furnished by the tender, permits the reduction of speed to be carried a little farther in that case. But the advantage from this point of view, comes only to the realisation of the equivalent of the tank-engine; it is thus solely under circumstances in which that is not applicable, that the other solution may be admitted, in spite of its complication, and its imperfection from the point of view of the use of the steam.

"When the steep gradients are accumulated at one point", says M. *Vuillemin* (*), " they are run over without great difficulty, either by sending the trains up in two parts, or by adding an auxiliary engine in front or behind; but when the gradients are spread over different points of the line, and the line is of considerable length, the two following cases are presented in the working of the traffic :

" Either the load of the train is such that a single engine can run over the whole line,

(*) Autographic note.

and restricted as regards the passage of the steepest gradient; in this case the engine is badly utilised on the portions of the line with down inclines, and on less steep up gradients, where the load might be much more considerable.

"Or the train is made up with the view of the use of an auxiliary engine; in that case, this latter becomes useless on the horizontal portions, on the down inclines and flat gradients. It is thus obliged to run useless distances, not only for drawing the train, but also in returning to its starting point. This return empty becomes very embarrassing on single lines, when the traffic is somewhat developed thereon, and causes as much trouble as the running of a train.

"There would thus be an interest, for working these lines of uneven section, with steep gradients spread over the whole length, to avoid the employment of two engines, and to find one engine which could, *at a given instant*, develop a more considerable tractive power, by utilising the adhesion of the tender and its supplies of water and fuel.

"The Company of the Eastern of France having to work lines of this kind running to the coal basins, and where the traffic will be important, has thought proper to have some engines constructed with working tender, the original idea of which belongs to M. *Verpilleux*.

"In working out the engine of the Eastern of France, the engineers have given the greatest attention especially to insure a great production of steam. This is the chief point, for it is a question of, *at a given moment and during a pretty long time, furnishing the steam for two locomotives by means of a single boiler.*"

This statement is somewhat wanting in precision. M. *Vuillemin* seems certainly to admit what is in reality, in the case in question, the sole and unique justification of the engine, that is to say that it ought to proceed by spurts : but he seems to fear saying so formally.

Following these somewhat vague terms " at a given moment, during a pretty long time ", the *note* returns to the charge, but without being much more explicit; after having stated that the production of steam is as high as 14.600 lbs per hour, it adds :

"With such a quantity of steam, and according to the dimensions of the cylinders of the two motors, the boiler is able to supply sufficient steam to run the two motors at a *sustained* velocity of 11,18 miles an hour, *during the time necessary for ascending the gradient.*"

Is it always a question of spurts? And up to what limit of length are these possible? On the line from *Forbach* to *Niederbronn*, between *Sarreguemines* and *Bliesbrücken* is an incline of one in 66,7, six miles in length. But can it be admitted that an engine can properly attack such a gradient, if its elements are not proportioned in such a manner that it may produce as much as it expends, just as much as if it were a question of a gradient two or three times as long?

This proportion necessary, the system is nothing else than one means like another, better or worse according to the cases (doubtless rarely better) of utilising the adhesion of the fuel and water without carrying these on the engine itself. Comparing the engine, from the point of view of its power and of its weight to an ordinary engine of less power, with an auxiliary, the note objects that the latter would only be utilised on a small portion of the distance run. But is it not the same thing with respect to the excess of power and of weight of the single engine with working tender? As to the return, doing no work, of the auxiliary, that is not an obligation; it is a faculty which is made use of if desired for the auxiliary, while it is interdicted for the excess of power and weight which, in the engine with working tender, represent the auxiliary.

These are the principal eléments of the Eastern of France engine :

Engine...	Heating surface.	Fire-box	123,94	159,99
		Boiling tube	36,05	
	276 tubes 1,93 inches external diameter, 0,098 of an inch in thickness and 9,84 feet long			1.179,44
			sq. ft.	1.339,43
	Certified pressure : 10 atm.			
	Cylinders 16,54 inches by 23,62 inches stroke.			
	Wheels 4,26 feet in diameter.			
	Weight	Empty		29,5 tons
		Full		35,0 »
Tender...	Cylinders 14,96 inches, by 16,54 stroke.			
	Wheels 3,94 feet in.			
	Weight	Empty		17,00 »
		Full		28,00 »
	Total weight			63,00 tons all adherent.

The engine and the tender both have inside cylinders, which are consequently a little inclined.

The values of the function $\frac{d^2 l}{D}$ are to each other in the ratio of 1,62 to 1; while the maxima weights : 35,0 and 28 tns, 0, only in the ratio of 1,25 to 1; and in reality the ratio of the respective efforts of traction, measured on the pistons, exceeds 1,62, the admission pressure being greater for the engine than for the tender. But the weight of the engine is invariable, while that of the tender diminishes; and besides, if it were desired to place the total tractive effort in due relation with the adhesion, which is always in excess, the production of steam would not be sufficient.

402. *Engine of the Central Belgian line.* — The same type has been adopted by the Central Belgian for working the inclines of one in 55 on the portion from *Givet* to *Lodelinsart*. The " *Verpilleux* " (Pl. LXX *figs*, 2 and 3) constructed in the *Louvain* shops, draws on that portion of the line trains of 246 tons, engine not included, at the speed of 12,43 miles an hour. It has even drawn thereon 300 tns, 7 at 11,81 miles an hour.

Heating surface	Fire box		104,41 sq. ft.
	Tubes (367 of 11,48 ft.)		1.844,53 »
			1.948,94 sq. ft.
Engine	6 wheels of		4,0 feet diam.
	Cylinders : 18 inches diam		24 inch stroke.
Tender	6 wheels of		4,0 feet diam.
	Cylinders 13,75 inches diam		15,75 inch. stroke.
	Weight	Engine full	35,8 tons
		Tender, with 8,10 tons water, and 4 tons coal	26,9 »
		Total weight	62,7 tons

In the first application, that on the *Saint-Étienne* line, which was more complete than those which have been tried since, the exhaust steam was returned to the chimney, and thus contributed to the draught.

In the Eastern of France engine, this steam is sent out directly into the air. In those of Mr. *Sturrock* it was utilised for heating the water. In the Belgian engine, this steam can either escape directly by a chimney placed behind the tender, or heat the feed water. The temperature to which it can be brought is limited since the pumps have been replaced by *Giffard's* injector, which admits only of a low temperature of the feed water, about 95° F. to avoid the risk of compromising the condensation of the steam by its mixture with the aspired water, that is to say the very principle of the return of the mixed jet into the boiler. If the feed water is desired to be much heated, which is often useful, as well as to retain the advantage of feeding while the engine is standing, a pump should be applied in addition to the *Giffard*, worked by a small donkey engine. This is what has been done at *Louvain*, replacing the valves by slides.

The heating surface is very considerable; it suffices for the regular normal supply of the four cylinders. This great surface was obtained not by the length of the tubes which is very moderate : 11 ft, 48, but by a greater number of them. They occupy in the barrel of the boiler, a portion of the space ordinarily devoted to the steam, for which there is a complementary receptacle R, R.

403. *The engine with working tender is a solution in a certain way, from the point of view of curves.* — This engine with working tender has only been applied to lines which are not very difficult on plan; the consideration of curves has been quite foreign to the motives alleged in its favour by its partisans, not very numerous however; but if there is one consideration which can be invoked in certain cases in favour of its principle, it is that. If the weight of the trains and the inclinations of its section require powerful and consequently long and heavy engines; if the low speed requires the total adhesion not only of the weight but also of its supplies of fuel and water and consequently of its tender; if the engine cannot carry its own water; if, in fine, on account of the bends in the line on plan, the parallelism of the axles between which the weight ought to be distributed is inadmissible, we find ourselves confronted with the problem more or less solved by the *Steierdorf*, *Seraing*, *Wiener Neustadt*, *l'Avenir* engines, and by those of Mr. *Fairlie*.

The engine with working tender is nothing else, in effect, but a solution of this problem : to transmit the rotation between two groups each formed of parallel axles, but able to converge. In that case the four cylinders ought to be considered as working normally, and the elements of the engine should be proportioned in accordance.

From this point of view of running on a curve, the principle cannot be absolutely condemned *a priori*, in spite of the objections it raises. We can hardly hesitate to recognise it as more practical (which is not saying much), than that of the only solution which exists of the *Engerth* engine, that is to say the *Steierdorf*. But if the comparison be established between the engine with working tender, and the tank-engine with two articulated frames and four cylinders, it appears greatly to the advantage of the second; the solution is more complete from the point of view of curves, seeing that in the first, the boiler is supported by a single group of axles all parallel.

404. *Partial or total utilisation, for the adhesion, of the load drawn.* — When the adhesion due to the weight of the motor altogether, that is to say the weight of the engine itself and of its supply of fuel and water with or without tender, is not sufficient, the idea quite naturally presents itself of obtaining from the load itself the necessary complement of the adhesion. This idea can be realised, either by driving the wheels of a part or of the whole of the vehicles of the train, or in certain cases, enciting on the same vehicle, the motor and the load itself.

The first contrivance was pointed out by M. *Séguin* senior, as far back

as 1839 (*); but a false principle could never take hold seriously of so exact a mind. Later, the same expedient was presented as a solution applicable to the crossing of chains of mountains by great lines. It hardly stands a somewhat careful investigation, in spite of whatever speciousness there may be at first sight, in making of the whole train an immense engine carrying its useful load, and thus to have only for absolute limit of the inclines, the coefficient of adhesion itself, or $\frac{1}{7}$ about.

But whatever may be the system of the engine; whether its mechanism be grouped, in the ordinary way, on one single vehicle, or disseminated throughout the whole extent of the train, as has been proposed in order to render all the vehicles motors, this engine will always have the weight corresponding to its power; it will be indeed much enhanced in the second case, whatever may be the details of execution. The ratio, so unfavourable, as we have seen, of the dead weight to the useful load, will thence be more unfavourable still, gradient and velocity being equal, with this disseminated motor, than with the motor grouped in one; the sole advantage of an arrangement permitting the adhesion of the load drawn to be utilised, that of a greater reduction of speed, and consequently of a greater correlative increase in the tractive effort, would thus be singularly reduced by the increase in the dead weight of the motor, arising from its dissemination; that advantage would besides be compensated for by great drawbacks, not to say real impossibilities.

That the motor should vary according to the conditions of the line, is quite reasonable: one engine is taken off, another one is put on; but to apply cylinders and complicated mechanism to carriages and waggons, and make regular engines of them, is, not to take into account the difficulties of realisation, the most unfavourable use of the steam, its inevitable condensation, the chance of continual derangements, etc., to specialise and localise the rolling-stock, just as the motive stock is localised. Thence, independently of the elevated cost of this stock, the necessity of transshipment, with its deplorable economical results.

A useful effect reduced still further, on account of the greater weight of the motor thus *scattered about*, a very costly stock and transshipments, these are, beyond the difficulties of detail which experience would not fail to bring out, the grounds which absolutely condemn the solution in question, as the solution of the problem of traction up steep gradients.

(*) *Des chemins de fer*, pages 438 and following.

Restricted to the installation, on one and the same vehicle, of a motor of small power, and of its useful load, the principle retains no longer anything inadmissible; the *steam carriage* is already old. It is more than five and twenty years since Mr *W. Bridges Adams* applied it on one of the branches of the *Bristol* and *Exeter* line; and before that Mr *James Samuel* had introduced it on the Northern and Eastern (now part of the Great Eastern system). These first trials did not succeed, it is true; they failed in the execution; the arrangements for the passengers were exceedingly inconvenient. But since 1865, *steam carriages* have become more and more in vogue in the United States, on the lines of small traffic and short journeys. Such a vehicle containing 40 comfortable places weighs little over 14 tons.

It would often be useful to give the motor a slight excess of power, in order that it might at need, draw in addition a sort of tender. The system would thus possess without losing its character, an elasticity in keeping with the inevitable small oscillations of the traffic.

It is especially, however, on steep gradients that the concentration of the motor and the load is grounded; and even then, there must be quite peculiar conditions of traffic, to cause the advantages, so evident in general, of the independence of the motor and the load, to be given up.

Mr. *Fairlie* has studied several types of *steam carriages*; one of them was constructed and tried on the Metropolitan, in 1869. The frame is supported at one end by four wheels coupled, and at the other by an American bogie. Behind is the passengers body containing 66 places; in front the vertical boiler on *Field's* system, the bottom plates of which, strengthened and prolonged by others passing below the grate and the frame, form the pivot of the leading truck. This large pivot is taken by a collar fastened to the longitudinals of the articulated truck. The general frame carries the water tanks, which indeed form an integral part thereof.

The base was limited by the condition of having to turn on a table 40 feet in diameter. The chimney, too high on account of the vertical boiler, is lowered like that of a steamboat, when passing through over works.

CHAPTER XIII.

EXAMPLES OF GRADIENTS WORKED BY LOCOMOTIVES UTILISING THE ADHESION DUE SIMPLY TO THEIR WEIGHT.

405. Before examining the systems which seek, for the transmission of the effort of traction, to complete or supplement the adhesion due to the weight, it is expedient to pass in review the principal examples of lines with steep gradients worked by locomotives under normal conditions. The atlas of plates includes either the trace and the longitudinal section, or only the section, at times very much reduced, of a pretty large number of lines, remarkable at once by the difficulties which the construction had to overcome, and by those which it could not avoid the legacy of to the working. The scale of heights is only ten times that of the horizontal distances. This is a low ratio, and scarcely sufficient to show out the variations in the section; but it was necessary to make it uniform to facilitate comparison at first sight, and a higher ratio would have been very inconvenient to apply to those sections which go to considerable heights.

We do not hesitate to enter into some detail, although often incompletely, either as to the lines contained in the atlas of plates, or as to others, which it had not been able to include, from want of sufficient particulars. The more it is impossible to formulate general conclusions, the more material it is to place under the reader's eyes, documents the application of which he can make himself, to the particular problems before him, and to furnish him, failing the solution itself, with some of its elements.

406. *Gradients less than one in* 70. — Gradients lower than one in 70 are now-a-days so numerous, that they do not require to be dwelt upon, unless the line presents some particular circumstances, such as curves of very small radius. It is on this account that the line from *Heidelberg* to *Würtzburg* deserves to be noticed. The inclines at the passage of the *Odenwald* do not exceed one in 80, but the curves descend to 110 yards. The service is done by engines, constructed at *Karlsruhe,* having 1378,74 square feet of heating surface, 81,81 square feet only of which is direct; cylinders 1,5 × 2,08 feet; with six wheels coupled 4 ft, 0; weighing empty 30 tns, 4, and full 35 tns, 0. The distance between the axles is 11 ft, 32; nothing

has been done to facilitate the running through the curves of 110 yards.

407. *Gradients of one in* 71. — The line from *Bilbao* to *Tudela* (Pl. XCII) a result of local promotion, a noteworthy thing especially in Spain, arrives at the foot of the Pyrenees by a series of gradients which reach one in 80 for a short length, and it crosses these mountains at the height of 2.047 feet by gradients of one in 70 only, passing the summit by a small tunnel. As the plan shows, this line was able to be very conveniently developed along the sides of a sort of circus, which it enters through a narrow defile, towards the 23rd mile, and whence it emerges almost on the same vertical line, after having made a circuit therein of 7,5 miles, and thereby gained a height of 374 feet.

408. *Gradients of one in* 66,7. — The *Northern of Spain* line (Pl. XCIII, XCIV and XCV) offers another remarkable example of an iron road crossing two mountain chains, and rising on one of them to a very great altitude, without exceeding a very moderate inclination : in this case one in 66,7.

The line arrives from *Irun* at the foot of the Pyrenees, at *Beasain*, at 512 feet, and crosses the principal summit of the neck of *Otzaurte* at 2.014 feet, by a tunnel 1.266 yards long, after having above *Cegama* passed a spur by a tunnel of 3.226 yards; it descends to *Olozagoitia* at 1.725 feet, crosses the Ebro at *Miranda*, at 1.512 feet, arrives at *Pancorbo* at 2.066 feet, rises to 3.117 feet to pass from the valley of the Ebro into that of the Douro, traverses the immense plateau of Old Castile, reaches *Avila* at 3.714 feet, rises on the Guadarrama, the crest of which it passes by the Canada tunnel at the height of 4.462 feet, redescends to the *Escurial* at 3.045 feet, and reaches *Madrid* at 2.100 feet. These principal figures, which appear exact, are not quite in accordance with those of the longitudinal section, taken however, from original documents. The plan of the line is favourable; the radii of the curves do not descend below 328 yards and indeed not below 437 at the crossing of the Guadarrama; but on account of the gauge of the line (5 ft, 68 to centres of rails), this radius of 328 yards is only equivalent to a radius of 284 yards with the 4 ft, 9 gauge.

This trace, relatively advantageous for traction, was not obtained without great sacrifices, which the traffic is far from warranting, and which it will be long of warranting. Assuredly here was a case for great economy in establishing the line; but at the period when French capital went to engulph itself in the deserts of the Peninsula, the most naive illu-

sions were indulged in, which strange arguments came in, besides, to support. In the first days of the working, the receipts were extolled as magnificent figures for a beginning, full of promises for the future. These receipts were what the railway was paying itself for the organisation of its own service; their elevation was only the expression of a sad reality, the destitution of the districts it had been constructed to supply!

The engines with eight wheels coupled (Pl. XLIX to LII), draw on gradients of one in 66,7, with a slight reduction of speed, the trains drawn on the ordinary portions of the line, by the six wheels coupled engines, of the 33 tons, *Bourbonnais* type.

The line from *Moulins* to *Montluçon* (Pl. XCVI) is an interesting example of a line with long gradients of one in 66,7 and with a very serpentine trace; but the curves are of moderate sharpness. The radii are almost always 547 yards, only and by exception 437 yards, and in one single case 328 yards. The line is worked by two types of engines:

1. With six wheels coupled, 3 ft, 80 in diameter.

Heating surface............	Fire box...............	79,22	1.514,42 sq. ft.
	Tubes..................	1.435,20	

Pistons 1,48 × 2,13 feet.
Weight full: 36 tns, 3. Tender 18 tons.

Load drawn on a gradient of one in 66,7 at the speed of 9,32 miles an hour, 216 tons.

2. With eight wheels coupled (259).

Load drawn on one in 66,7 at 9,32 miles an hour, 254 tons.

The line from *Forback* to *Niederbronn* (Pl. CV, fig. 1) presents a remarkable succession of gradients up and down, with one in 66,7 for limit; it is one of those to which the engineers of the Eastern of France thought the engine with working tender (399) would be applicable with advantage.

The same plate indicates the principal changes of gradient on several lines having also one in 66,7 as limit; namely *fig.* 2, *Mezières* to *Hirson: fig.* 3, *Chaumont* to *Pagny; fig.* 4, *Chaumont* to *Châtillon; fig.* 5, *Livron* to *Privas; fig.* 6, *Lyons* to *Grenoble; fig.* 7, *Châlons* to *Sainte-Ménéhould*.

Let us notice, on the line between *London* and *Birmingham*, an incline of one in 66,7 for 1,64 miles, between *Euston Square* and *Camden Town*. At first worked by a rope, it has been worked by locomotives since 1849, a period when indeed the locomotive had already for several years, taken

possession of the much steeped gradient at *Lickey*, on the *Birmingham* and *Gloucester* line.

409. *Inclines of one in* 62,5 *to one in* 55,5. — One in 62,5 is the limit on the line from *Montauban* to *Rodez*, but it is only reached on a small portion of the distance; the trace is however very serpentine; the radius of the curves descends to 328 yards.

The Belgian railway of the Grand Luxemburg has long gradients of one in 59,9, with curves of 328 yards. From *Jemelle* to *Libremont*, the summit of the line, is found the longest gradient, continuous for 20 miles; it is also the most tortuous part of the trace. Engines with eight wheels coupled, with cylinders 1 ft, 57, 2 ft, 16 stroke, weighing full, tender included, 66 tons, draw 310 tons on the gradients of one in 59,9.

The service was previously done by engines with 6 wheels coupled with heating surface of:

Fire box....................	98,70 sq. ft.	1.336,50 sq. ft.
Tubes......................	1.237,80 »	

Weighing empty 31,5 tons, and full 35,5 tons, thus distributed :

Leading axle................................	12,0 tons
Middle do..................................	12,0 »
Trailing do	11,5 »

They drew, it was said, at 16,64 miles an hour, 190 tons (the tender of a score of tons not included) a figure which seems very high for that speed. It corresponds, in effect, admitting a resistance of 13 lbs, 23 per ton (which is very moderate, on account of the curves) to an effort of traction on the driving wheels of $(190 + 20 + 35)(16{,}7 + 6) = 5{,}57$ tons, or $\frac{1}{6{,}3}$ of the adherent weight, and an amount of effective work of $5{,}56 \text{ tons} \times 18{,}24 \text{ feet} = 101{,}41$ foot tons per second, or 0,30 horse power per foot of heating surface (*).

The line from *Naples* to *Foggia* (Pl. XCVII) crosses the Apennines under relatively easy conditions, at the altitude of 1.798,6 feet. The inclination does not exceed one in 59, and that limit is only reached on one side only, and for a length of 2 miles; it is true that this incline is in tunnel for 1,6 miles

(*) In his work: *Les locomotives et le matériel de transport à l'Exposition de* 1867 (*Paris, Dunod*, 1867), M. *E. Taillard* goes a great deal farther. According to him (page 7), the engine in question would draw up gradients reaching one in 50, " 19 loaded waggons at 10 tons each, besides the tender, at a speed of from 16,64 to 19,75 miles an hour ". The effort of traction would thus be as high as 8 tns, 84, that is to say to the quarter of the adherent weight, and the work per square foot = 0,4 horse power. If the engines really did this work, it could only have been accidentally, under very favourable circumstances, and not in regular running.

(*fig.* 1, mileposts 41 to 33). As to the curves, they are very numerous, but their radius only goes down as low as 437 yards at a few points.

The Norwegian line, on a gauge of 3 ft, 5, from *Christiania* to *Trondhjem*, crosses the Scandinavan Alps at the altitude of 2.261 feet, with gradients of one in 57.

Let us notice also, in this series, the line from *Lausanne* to *Berne*, with gradients of one in 55; in spite of this somewhat considerable inclination, the working is done satisfactorily by American engines, that is to say with partial adhesion. It is moreover, as we have seen, not a question of inclination, but one of speed, which in this case does not go too low. Starting from *Lausanne*, the line rises continuously on one in 55 for nine miles; beyond that the inclines do not exceed one in 82,5. Half the distance is on curves.

The engines with four wheels coupled (Pl. LXXX, *fig.* 3) constructed at the *Olten* shops of the Central Swiss, carrying their fuel and water, weigh in running order 40 tons, on which on the level, 25 tons on the coupled wheels, and 15 on the bogie in front. But on an up-gradient of one in 55, this distribution is considerably modified by the displacement of the water, in a direction favourable to adhesion, while on the level, the 15 tons in front insure the stability.

These engines draw:

1. On gradients of one in 100 to one in 82,5 :

At 14,91 miles an hour, 175 tons; at 24,85 miles, 125 tons.

2. On gradients of one in 55 :

At 9,32 miles an hour, 120 tons; at 12,43 miles, 90 tons; at 16,64 miles, 60 tons.

Line from Chauny to Saint-Gobain. — This little line of 9 miles (Pl. C, *figs.* 5 and 6) terminates towards *Saint-Gobain* by an up gradient 2,36 miles long, of which 2,17 miles are one in 55, with curves of 300 yards.

In the station the line presents an S curve of 137 yards radius, and in the works themselves, it describes a half circle of 87,5 yards, on one in 40.

The service is carried on by the engines with eight wheels called the Northern of France steep gradient engines (type of 1859), with a wheel base of 12,47 feet, which run also on the curve of 87,5 yards in the works.

An engine with twelve wheels coupled of the Northern of France (262) started up the one in 55, both hauling and pushing, with a train of 250 tons, increasing in speed, too, as it neared the top. The passage of the 137 yards

curve in the station was done without difficulty; the extreme axles of each of the groups had a total longitudinal play in their brasses of 2 ins, 36 (331) providing for the versed sine of the wheel-base on a curve of 164 yards.

Estimating at 13 lbs, 23, on account of the curves, the resistance per ton, on a level, we have:

Train.............	$250 \times 13{,}23 \times 4 = 6{,}00$ tons	7,44 tons
Engine............	$60 \times 13{,}23 \times 4 = 1{,}44$ »	
Adhesion, taking $\frac{1}{7}$............................		8,59 tons

L'*Apennin* engine (332,6) with wheel-base of 13 ft, 12, with a total play of each in the four axles of 1,97 inches, and with compensating beams between the first and the second, and between the third and fourth, passed under my own eyes, very easily, without the flanges gripping, through the curve of 87,5 yards, in the works.

The Northern of France thought it would be of advantage to subject one of its four cylinder engines with wheel-base of 19 ft, 68 to the same test, at the same time applying thereto the same arrangements as in l'*Apennin*. It is that which was alluded to farther back (332, 6, and 333; also Pl. LXII, *figs.* 2 to 5).

The engine placed behind the little train, pushed it through the 87,5 yards curve and up the one in 40; arrived at the end, the brakes were tightened and caused the six axles to slip in their places, thus proving the freedom of their flanges. Several manœuvres forwards and backwards also placed in evidence the relative freedom of the system on that very sharp curve.

The same engine drew up the one in 55 a train of 267 tons at a mean speed of 9,07 miles an hour, violent slipping taking place for 0,62 miles; but afterwards it brought up its speed to between 10,56 and 12,43 miles.

Following these trials, the engine did the whole of the work between *Chauny* and *Saint-Gobain*, for several days running through the 87,5 yards curve as easily as the *steep gradient* engines, devoted to the service of the line.

" That is ", M. *Petiet* added with reason (*), " a most important result, when it is found to be one of the most powerful locomotive working normally, without any necessity of adopting the complication involved by the articulation of the frame ". We may add that the engine ran very smoothly and most steadily on the descent to *Chauny*, at a speed of 16,64 miles, a very considerable speed for wheels of only 3 ft, 47 in diameter.

(*) *Annales des mines*, 5th series, vol. V, 1864, page 155.

The *Dom Pedro II* railway, on a gauge of 5,25 feet, connects in the first place by a main line of 67,73 miles, *Rio di Janeiro* with the river *Parahyba* which it skirts for 60,69 miles. It encounters at a little distance from *Rio di Janeiro*, the *Serra do Mar* an abrupt escarpment which skirts the coast, with a height increasing towards the north, and which attains, at some points, 4.265 feet. It is less a mountain chain, than the edge, so to say, of a vast table land more or less broken, which dips gently towards the Parana. At the point where the *Rio di Janeiro* line arrives at the foot of this escarpment, its height is less than above *Santos* (410), and like a crest or upper ridge, was traversable by a tunnel, of 2.625 yards in length; the height is only 1.345 feet, the inclination of the gradients is one in 55, and the radius of curves 267 yards; but the tunnels and works of every kind are very numerous. The great tunnel of 2.625 yards, was only completed three years after the rest of that part of the line; and the communication was established temporally by an upper line, with very steep gradients, which will be noticed farther on (418).

The line is worked by American engines.

410. *Gradients of one in* 50. — Gradients of one in 50 are numerous; in England those of *Bradford*, *Leeds*, *Hunt's Bank* (Lancashire and Yorkshire line) have been worked by locomotive since their opening.

It is within this moderate limit that has been kept the most remarkable crossing of the Pyrenees, that of the line from *Santander* to *Alar del Rey*, the point at which it joins on to the Northern of Spain railway, after a distance of 86,36 miles on which it gains an elevation of 2.795 feet. The culminating point, *Pozazal*, is at 61,51 miles from the station of *Santander*, at an altitude of 3.228 feet.

The section from *Barcena* to *Reinosa* (Pl. XCVIII) is especially remarkable: separated as the crow flies by a distance of 9,64 miles, there is a difference of level between these two points of 1.834 feet, which is spread over a length of 19,13 miles, or a mean rate of inclination of one in 71,4. Between the 42,25 and the 51,57 miles, there is only, as the crow flies, a mile and a quarter, for a difference of level of 820 feet; but with a development of 9,32 miles, a gradient is obtained of one in 59, on the average.

Curves of 380 yards and of 328 yards are numerous. Beyond *Barcena*, situated at 6,2 miles from the culminating point (3.218 feet) and at 438 feet lower (that is to say within about 7 feet of the height of *Alar del Rey*), the line enters into quite ordinary conditions.

The *Vaessen* engines with *Bissel's* truck weighing 46 tons (341, and

Pl. LXIII and LXIV) draw, it is said, on gradients of one in 50, 200 tons at 12,43 miles an hour. Assuming, by reason of the curves a resistance of 11 lbs. a ton at this speed, the tractive effort is 246 $(44 + 11) = 6{,}10$ tons, or $\frac{1}{6}$ of the adherent weight, which is 37 tons at the most.

As to the work done by the engine, it will be $6{,}10 \times 18{,}24 = 111{,}26$ foot tons per second, or 453 horse power and $\frac{453}{1.495} = 0{,}304$ horse power per square foot of heating surface; a considerable figure.

Line from Mouchard to *Neufchâtel* by *Pontarlier* (Pl. CV *fig.* 9). This line which crosses the Jura at a height of 3.084 feet, has a continuous gradient of one in 50 per 10,56 miles, with curves of 437 and even 383 yards. The line thereon is worked by engines with six wheels coupled (*Bourbonnais* type), 53 tons empty and 37 tons full, which draw 150 tons at 9,32 miles an hour (156 tons according to the loading tables).

The line from *Arvant* to *le Lot* (section from *Figeac* to *Aurillac*) presents, between *le Rouget* and *Maurs*, a long incline of one in 50.

The line from *Orawitza* to *Steierdorf* (Banat) 18,84 miles, connects the coal basin and the works of the Banat with the state lines in Austria (Pl. CIV). It only rises 1.204 feet, but there are 10 miles of one in 50, and numerous curves coincident therewith of 136 yards, circumstances which originated the trial of the ingenious, but in no way practical type of the *Steierdorf* (355).

411. *Gradients above one in* 50, *and lower than one in* 40. — 1. The incline from *Wienenburg* to *Hartzburg*, on the *Brunswick* and *Hartzburg* line has for 5 miles an average inclination of one in 77 only; but it goes up as high as one in 46, for a very short length it is true, 580 yards only. It deserves to be noticed, as it has been famous. Worked at first by horses, since 1853 it has been worked by locomotives with six wheels coupled (*) ordered from *Stephenson*.

The *Vale of Neath* Railway, from *Neath* to *Brecon* (Wales), rises 1.312 feet in 15 miles, or with a mean gradient of one in 60, to pass from the vale of *Neath* into the valley of the *Usk*. The *Glis Neath* incline is one in 47,6 for 5,20 miles. The tank engine with eight wheels coupled alluded to (332.1), weighing 56 tons, draws up that incline 300 tons, excluding its own weight.

(*) *Lechatelier, Chemins de fer d'Allemagne*, 1845, page 96.

The branch already spoken of (382) from *Aubagne* to *Valdonne* where the gradients also reach one in 47,6, is worked by engines with six wheels coupled, with from 1.000 to 1.086 square feet of heating surface, weighing from 28 to 30 tons, with 11 ft, 25 wheel base, and drawing, the ones, as we have seen, 93 tons, and the others 102, tender not included, at a speed of 6,2 miles an hour, but which might be however raised to 9 or 12 miles; as, by the way, the load-tables allow.

The *Daintos* incline on the *South Devon*, one in 45 on the main line, on which the double traffic both high and low speed is considerable, has been long worked by locomotives; as has also been the one in 43 which runs into *Halifax*.

One of the oldest inclines, and on that account very well known, is from *Geisslingen* to *Ulm*, one in 45, and 3,54 miles long, with curves of 300 yards radius.

An engine with coupled wheels 3 ft, 94 in diameter, weighing 34 tons draws up that gradient 109 tons at 15,53 miles an hour. On the other side, where the gradient is one in 62,5 for 43,4 miles, the load drawn is 151 tons.

The line from *Baltimore* to *Ohio*, has a similar gradient 11 miles long; as far back as 1854, as we have said (258) Mr. *Winans* had constructed, for the passenger service on this gradient, a locomotive with twelve wheels, eight of which were coupled, 3,50 feet in diameter, and a fourwheeled bogie. Twelvewheeled engines thus date from far back. The pistons had a diameter of 1 ft, 80, and the same stroke.

This type has been replaced by engines with ten wheels, six coupled, and four carrying a bogie truck.

The little line from *Carson City* to the mines of *Virginia City* (Nevada) of 23,13 miles in length, has a constant inclination, one in 45, and curves of 42 yards radius. It is worked by means of engines, constructed by *Booth* and *Co* of *San Francisco*, the principal elements of which have been given above (344); but the load drawn is not known.

Valparaiso and *Santiago line* (*one in* 45). *Chili* occupies, as is well known, a long stretch of coast, the breadth of which at no part exceeds 14 miles, and which is bounded on the East by the Andes mountains. Immediately from *Valparaiso* the line rises with gradients of one in 100, one in 50, and lastly the steepest that of *Tabor*, one in 45, is 6 miles ong, with continued curves the radius of which goes down to 200 yards. The principal work on this line, the wrought iron viaduct at *Maquis*, on cast iron piers, presents the double feature of being on an incline of one in 45, and on a curve of 200 yards.

The line had to encounter at *San Pedro*, a granite spur of the Andes, which had to be pierced. In spite of the slight length of the tunnel, 523 yards, the execution of the work, delayed by various causes, was very long; the example of the Blue Mountains was followed (418) by establishing a passage above, with inclines of from one in 15 to one in 13; which however were worked by stationary engines. This temporary service lasted four years, up to 1863, when the tunnel was finished.

The project of an iron road, starting from *Buenos-Ayres*, traversing the Argentine Republic, the Andes, and ending on the coast of Chili, dates back now several years. The length of the interoceanic railway would relatively not be considerable, less than 1.200 miles; some portions are already made, and it is asserted that the question of completing the line is seriously entertained. The elements of traffic would not fail; what is wanting is that energetic race which goes on revivifying and transforming everything in North America, making war, and making it terribly when necessary, devoting thereto all its ardour and its industrial science, powerful otherwise than a superannuated military art, and striving, no sooner the war over, to take again to peaceful works, the sole end of life.

The *Edinburgh* and *Glasgow* line has a well known incline, that of *Cowlairs*, one in 45, and 1,61 miles long. It was worked at first from 1842 to 1845, by a stationary engine with a fixed rope. The rope being so little durable, locomotives were tried: they had cylinders 15 ins, 75 by 25 inches, wheels 4 ft, 33 in diameter, and drew from 80 to 100 tons. But in 1849, a return was made to the rope, replacing the hempen one by a metallic cable, and this is still adhered to. The inclination and shortness of this gradient render the economical working of this arrangement doubtful; but it appears that the cause which determined the exclusion of the locomotive, is that the incline being for one half its length in tunnel, the steam and smoke provoked continual complaints from the passengers, and the more so on account of the frequent slipping which took place.

But for this special difficulty of ventilation (370) more disadvantageous conditions are found in many cases, at the Hauenstein (411) for example, without the locomotive having been put in question for a moment; but this return to the stationary engine, at *Cowlairs*, is not the less a remarkable fact, and one which should cause the uncompromising partisans of the locomotive to reflect; we believe that the stationary engine, especially with a simple cable and direct traction is not in its place at the *Cowlairs* incline; but we do not believe the locomotive to be any more in its place

on a great number of inclines, much steeper than this, which it is made to work.

In any case, the inclination and the length are not the only elements to be considered. The position of the incline should be fully taken into account. An incline with stationary engine on a main line far away from an important station would involve great disadvantages, while if it ended at a terminus there would be few.

It is thus that the working by stationary engines of the three inclined planes, in tunnel, from *Edge Hill* to *Liverpool* has continued for a very long time, in spite of their moderate rate of inclination (one in 48, one in 90, one in 55). The two first, set apart for goods, terminate at the docks of the port, and the third for passengers goes into the town. Their joint length is 1,49 miles; the activity of the traffic, and, consequently, the great precipitation of steam, greatly lower the coefficient of adhesion.

Pacific Railway (Pl. XCIX). Out of the total distance, 3.274 miles, from *New-York* to *San Francisco*, the portion between *Omaha* on the Missouri and the coasts of the Pacific is specially called the *Pacific* line; it is 1.707,6 miles long, and is divided into four sections :

1. From Missouri to the Rocky Mountains;
2. From the Rocky Mountains to the Salt Lake;
3. From the Salt Lake to the Sierra Nevada;
4. Mountains of the coast.

Two Companies divided the work from *Omaha* to *San Francisco* between them : to the East, the Pacific Union; the Central Pacific to the west. Driving along the one towards the other with an ardour which had the most powerful stimulant (for the line laid, it was quite a territory and a subvention conquered) they met near *Ogden* (Utah) and that town is their joint limit.

The passage of the Rocky Mountains, by *Evans's* trace did not present great difficulties. The crest of the principal chain is crossed by an open cutting at the height of 7.282 feet, but the culminating point, which is that of the whole line, belongs to a secondary branch, crossed by a depression (*Sherman's Neck*) at the height of 8.248 feet, reached by inclines of one in 60, and curves of 333 yards.

At the Sierra Nevada, there is a summit tunnel, but only 164 yards long, at the height of 7.044 feet, and at 208,66 miles from *San Francisco*. The rate of inclination does not exceed one in 45, but the minimum radius of the curves goes down on the western side to below 218 yards.

On both sides of *Sherman's Neck*, peaks of 1.310 or 1.470 feet at least, rise

up. In the Rocky Mountains as in the Sierra Nevada, the limits of arborescent vegetation, and of perpetual snow are much higher than in Europe. Beautiful forests of vigorous pines are to be seen at the height of 8.200 feet, and at 9.800 feet, and the limit of perpetual snow does not commence until nearly 13.000 feet. The climate is rougher in the Sierra Nevada than in the Rocky Mountains, in spite of the lower altitude of the former; from September to May the thickness of the snow is often as much as 13 or even 16 feet. Thus the length of the galleries attains, in the Sierra, to nearly 50 miles; and these are not, as on the Rocky Mountains slight shelters, but massive constructions, so constituted as to resist avalanches; and even then they do not always resist. From the very outset of the working, in 1869, one of these galleries (*snow sheds*) formed of frames very close together of large trunks of trees, was crushed by an avalanche, near the *Summit* station. Towards the same period, a train was locked up in the snow, but got off with some days' delay, thanks to the wise precaution which had been taken to provide a supply of provisions, as for a vessel putting to sea.

This fact occurred again at the beginning of the winter 1871-1872, which was very severe in those parts. The storm bursting forth violently, drove up the snow on the line, and blocked up the trains; near *Sherman's Neck* among others, passenger trains took four and twenty hours to progress 4 or 5 miles. Passengers starting from *San Francisco* by the railway only reached *Chicago* at the end of twenty days; and as to the goods trains, they blocked up all the sidings. Thanks to the comfortable condition of the stock, especially of *Pullman's* sleeping cars (33 and foll.) the position of the passengers in these locked trains, is not very distressing. Well heated, well, even overabundantly provisioned, they can patiently await more clement weather; better arranged in this respect than European travellers boxed up in the confined compartments of a train destitute of all resources, but which at the same time ordinarily get off in such cases with a delay of not more than a few hours. The extension of the snow sheds will be the necessary consequence of occurrences of this kind. Even at present, however, the greater part of the Sierra Nevada is a sealed book for the railway traveller.

This passage should be greatly improved one day, perhaps before long, the execution of this project being connected with another of a more urgent character. A company has been formed for bringing into *San Francisco* the waters of the Tahoc (or Tahoe) lake, situated in the Sierra Nevada, at an altitude of 6.234 feet. A tunnel of about 3 miles in length will receive both the water conduits and the line of rails, which will have by this deviation

the triple advantage of 984 feet less to mount, a shorter distance by 14 miles, and, what is the main point, the avoidance of the region most exposed to the influence of the snow.

The haulage is done, partly, by *Fairlie* engines, constructed in the United States by *W. Mason*, at *Taunton*, *Massachussets*.

Heating surface	1.776 sq. ft.
Four cylinders	1,25 × 2,0 feet
Twelve wheels, diameter	3,50 feet
Weight	54 tons

With a mean effective pressure in the cylinder of 100 lbs on the square inch, the tractive effort amounts to nearly 11 tns, 5, that is to say, to over one fifth of the weight. Perhaps the ordinary value of the adhesion allows the engine really to develop this enormous amount.

The Pacific line will not long maintain the monopoly of interoceanic communication by railway. The Northern Pacific, in course of construction since 1870, starts from *Duluth* on Lake Superior, passes through the states of *Dakota* and *Montana* and separates into two branches at the frontier of the Idahs State, into two branches which will run, the one northwards to Puget Sund, facing *Quadra* and *Vancouver's Islands*, the other southwards to *Portland*, on the Columbia or Oregon river. These two termini will be joined by a line parallel to the coast, which will be extended towards the North. The Northern Pacific will be particularly a mixed line, Lake Superior being joined to the Atlantic by great navigable channels. Moreover, by a branch to *St. Paul*, capital of Minnesota, it will be in connection with the whole railway system of the United States. The conditions of the trace, and also in spite of the difference of latitude, of the climacteric conditions of this line are much more favourable than those of the *Union*. The chain of the Rocky Mountains, a great deal lower is crossed at 3.280 feet lower than *Sherman's Neck*. As to the Sierra Nevada, the railway line, following the valley of the Oregon, crosses that chain by taking advantage of the opening made by the river. These circumstances, the qualities of the port of *Puget-Sund*, the fertility of the territory passed through, with its mineral riches, will give a real importance to this line; but the thorough traffic will be without doubt retained by that line which directly serves the locality of *San Francisco*.

The Canadian line, from *Montreal* to the Pacific by *Ottawa*, the *Garry* fort, and the passage of the *Yellow Head* (crossing of the Rocky Mountains) will also be 373 miles shorter, and have an easier trace than the Union line.

In that case also the work is in hand, and the completion seems near.

An other project of transcontinental railway through the Southern states (line from *Memphis* and *el Pazo*) terminating on the Pacific at *San Diego*, tried to raise capital in Europe. Its carrying out has been met with difficulties on the part of some of the States, principally Texas, but these are not the only ones. The circumstances in which it has collapsed, at least temporarily, prove that republican integrity does not always preside in great affairs, on the other side of the Ocean; it is especially as regards railways that this painful truth comes out.

Gradient of one in 42. Mr *Fairbairn* cited, as long ago as 1851, as worked by locomotives, the *Accrington* incline on the East Lancashire line, one in 42 for a length of 2 miles. An engine weighing 43 tons with its tender, drew a load of 71 tns,6 up it at a speed of 6,83 miles an hour; a result certainly not very wonderful, but which has been greatly improved since.

The limit of one in 42 is reached on the branch line from *Clermont Ferrand* to *Thiers* (Pl. CV, *fig.* 11).

412. *Gradients of one in* 40. — One in 40 takes a great part in the trace of several important lines: it is the limit at the *Semring*, at the *Brenner*, at the crossing of the Apennines between *Bologna* and *Pistoja*, at that of the *Gevennes* by the direct line from *Paris* to *Nîmes* by *Langogne*, at that from *Marseilles* to *Gap* (Pl. CV, *fig.* 13), etc.

One of the first examples of this rate of inclination, and a most instructive example was the crossing of the *Fichtel Gebirge*, from *Neumarkt* to *Markschorgast*, on the Bavarian State railway (Pl. C, *figs.* 1 and 2). The *Fichtel Gebirge* separates the basin of the *Maine* from that of the *Saale*, one of the affluents of the *Elbe*. Immediately from the *Neumarkt* station the line rises by gradients of:

	one in 71	one in 40	one in 40,6	one in 25
For lengths respectively of......	1,03 miles	1,55 miles	1,11 miles	0,70 miles

Mean rate of inclination: one in 44,8; on the inclines the curves do not go below 480 yards. The passenger trains were hauled, from the commencement by engines with four wheels coupled weighing 23 tons, with separate tender; and the goods by engines with six wheels coupled of 26 tons, coupled on, when required, as auxiliaries to the passenger trains.

The first had 4 ft, 5 driving wheels, and cylinders 14 inches by 24. The second with 3 ft,5 driving wheels, had cylinders 16 inches by 24, with a

heating surface of 786 square feet. They carried over the barrel of the boiler, a reservoir of 300 gallons communicating with the tender, which was filled with water when the state of the rails and the load of the train threatened slipping, which causes a great waste of water. There was thus an increase of adhesion, and at need an increase in the supply of water; it is true that the second could not be taken advantage of without giving up the first.

An engine with four wheels coupled drew, tender included:

70 tons at a speed of 8,75 miles an hour;

an engine with six wheels coupled:

120 tons at 9,13 miles:

and two of these engines together:

170 tons at 9 miles, or 145 tons at 11,06 miles.

Line from Alais to *Brioude* (Pl. C). Two engines with eight wheels coupled draw on gradients of one in 40, and curves of 220 yards, 38 to 40 waggons, or 400 tons gross. The conditions of the trace, analogous to those of the Semring, as regards the limits of inclination and curves, are in reality heavier, on account of the greater altitude and of the numerous tunnels of small section on the gradients. The working of this line is, like that of the Semring, a striking justification of the engine behind. It proves that even in very sharp curves with pretty long trains, pushing behind is without danger. The staff had a good deal of trouble to get into the way of it, and the drivers of the hind engines drove with a certain hesitation through the curves of 220 yards. Their tendency moreover is always to push the least possible, whatever may be the nature of the line.

Brenner (Pl. CII). The mountain portion, that is to say from *Bolzano* (or *Botzen*) to *Innspruck*, a length of 77 miles. *Bolzano* is at an altitude of 860 feet; the service of the special engines with eight wheels coupled, does not commence before *Brixen*, at an altitude of 1.863 feet. The rate of inclination only reaches one in 40 on the northern side. Not to exceed it, a development at *Stafflach*, near *Steinach* (altitude 3.610 feet) in the valley of the Schmirn, an afffuent of the Sill, was necessary, by passing round partly in tunnel, the village of *St. Jodocus*. On the south side (valley of the Eisack) the gradient was reduced to one in 44, thanks to the development of the line, which in the neighbourhood of *Gossensass*, quits the valley of the Eisack, takes that of the Schlag, extends therein with one in 44, returns on itself, always on the same slope, by a curve of 330 yards, with incline of one in

66,6, takes up again the one in 44, and returns into the Eisack valley, after a development of 6,83 miles, gaining 761 feet.

Minimum radius of curves 310 yards; maximum altitude, 4.385 feet.

The summit is passed over at the very level of the ground.

The service is done by engines with eight wheels coupled, 3 ft,5, in diameter, with separate tender, with cylinders 19,68 inches by 24 inches, wheel base 11 ft,32, weighing empty 41 tns,25, and in running order 47 tns,3. The hind axle has a longitudinal play of 0,60 of an inch. The passenger trains, 77 tons, are drawn by one of these engines, and the goods trains, of a regulation weight of 369 tons, and 300 tons mean, by two engines, one in front and the other behind, at a speed of 9,32 miles an hour. The gross weight of a goods train may thus amount to 500 tons, namely:

Load drawn	369 tons
Two engines	94,6 »
Two tenders	36,4 »
	500,0 »

Estimating, with the locomotive engineer of the line, M. *Gottschalk*, the resistance at 13 lbs,23 per ton (a figure which would be too high for so low a speed, but for the increase of the resistance owing to the numerous curves of 310 and of 330 yards), we have for tractive effort, measured at the circumference of the driving wheels $(13,23 + 55,12)\, 500 = 34.175$ lbs $= 15,25$ tons, which at the speed of 9,32 miles an hour, corresponds to an amount of effective work of 850 horse power, or 425 per engine and about 0,2 horse power per square foot of heating surface; the adhesion utilised is $\frac{15.250}{94.600} = \frac{1}{6,2}$.

Line from Bologna to Pistoja (Pl. CIII). We have already cited this line, one of most remarkable existing. It is a series of works of art of the most varied nature, of very difficult execution, very successfully carried out, but constantly threatened by an intractable torrent the *Reno*, and particularly by the tributaries thereof. The service was first done: either by *Beugniot's* eight wheels coupled engines, the principal elements of which are:

Heating surface	Fire box	101,18	1.861,12 sq. ft.
	Tubes	1.759,94	

Inside cylinders 21,26 inches diam. 22,05 inches stroke.

1st axle	11,80	47,30 tons, adherent weight.
2nd and 3nd do.	23,60	
Trailing	11,90	

Tender :

Front..............	5,20	23,52 tons, with 7,5 tons of water and 2,5 tons of coal,
Middle.............	9,16	
Trailing...........	9,16	
		70,82 tons

and which draw 120 tons at 12,43 miles an hour; or by engines with six wheels coupled of the Bourbonnais type, weighing full 34 tons, and with their tender 51 tons, drawing about 100 tons at 15,53 miles an hour; burning 12 cwt from *Pistoja* to *Pracchia*, or 85 lbs, 3, a mile.

From *Pracchia* to *Porretta*, the consumption is almost nothing.

According to the information I received on the spot, the eightwheeled engines had a much greater relative consumption.

For some years, only four and six wheels coupled engines have been applied to the service between *Porretta* and *Pistoja;* the *Beugniot* engines having been taken away to the Giovi incline, in order to replace the four-wheeled twin engines which had become almost unserviceable.

These are the regulation loads :

ENGINES.	LOADS IN TONS AT SPEED OF MILES													
	13	16	19	22	25	28	31	13	16	19	22	25	28	31
	From Bologna to Vergato. Maximum gradient : one in 83.							*From Pistoja to Pracchia.* Maximum gradient : one in 200.						
4 wheels coupled and outside cylinders	116	114	112	105	96	87	76	»	»	»	»	»	»	»
6 wheels coupled and inside cylinders	179	169	152	134	117	102	»	»	»		»	»	»	»
6 wheels coupled and outside cylinders	290	273	240	208	180	«	•	111	103	85	69	55	»	»
	From Vergato to Porretta. Maximum gradient : one in 83.							*From Pracchia to Porretta.* Maximum gradient : 0,000.						
4 wheels coupled and outside cylinders	110	107	103	98	89	78	69	»						
6 wheels coupled and inside cylinders	166	156	141	125	108	92	»	»						
6 wheels coupled and outside cylinders	255	245	215	185	158	»	»	360						
	From Porretta to Pracchia. Maximum gradient : one in 40.							*From Porretta to Vergato.* Maximum gradient : 0,000.						
4 wheels coupled and outside cylinders	»	»	»	»	»	»		360						
6 wheels coupled and inside cylinders	»	»	»	»	»	»	»	530						
6 wheels coupled and outside cylinders	116	108	90	73	60	»	»	750						
	From Pracchia to Pistoïa. Maximum gradient : 0,000.							*From Vergato to Bologna.* Maximum gradient : 0,005.						
4 wheels coupled and outside cylinders	»							248						
6 wheels coupled and inside cylinders	»							373						
6 wheels coupled and outside cylinders	360							540						

In the case of two engines, the load is the sum of the loads of the two engines separately, diminished by 20 tons.

These loads are for the summer months. For the winter months (1st. Nov. to 1st. April) they are reduced 10 per cent.

It is unnecessary to say that gradients of one in 40 are neither run up at 25 nor even 20 miles an hour.

Semring. The line from *Vienna* to *Trieste* crosses between *Gloggnitz* and *Mürzzuschlag*, the *Noric* Alps (Semring), and between *Laybach* and *Trieste*, the *Julian* Alps. The limit of one in 40 is only reached on the Semring, on the northern slope, and on a total length of 2,91 miles; it is continuous

on 2 miles (Pl. CIV, *figs.* 1 and 2). The line of the summit is crossed at the altitude of 2.897 feet, at 1.516 feet above the station of *Gloggnitz* and at 7ft, 2 above the station of *Mürzzuschlag*. The radius of the curves is only as low as 208 yards, at one point, at *Eichberg*; other curves which were of the same radius have been successively brought up to 230 yards: and on the one in 40, the minimum is 311 yards.

More recently constructed than the Fichtel-Gebirge crossing, but much more tortuous on plan, the passage of the Semring became naturally the principal theatre for the experimental study of the new problem brought up by traction on steep gradients and on sharp curves.

As we have seen, the Semring competition, the works of the *Seraing* and of the *Wiener Neustadt* engineers, and of M. *Engerth*, have only resulted in the adoption on the Semring, of the solution chosen at first almost everywhere else, that is to say the locomotive with eight wheels coupled, but with separate tender.

The *Semring* engines weigh, tender included, 66 tons thus distributed :

On the 1st axle	12,00 tons	Adherent weight : 46,40 tons	
» 2nd »	11,35 »		
» 3rd »	11,30 »		
» 4th »	11,75 »		
Tender 1st »	9,00 »		19,60 »
» 2nd »	10,60 »		
		Total weight	66,00 »

They draw 175 tons at 9,32 miles an hour, up gradients of one in 40, and on curves of 210 yards. But in the case of bad weather, fog, or severe cold, this load may be reduced, even by 25 per cent, on the request of the drivers or running foremen. It often happens that the weather, fine on leaving *Gloggnitz*, gets worse and worse, as the train mounts. Thus the station masters have to signal the state of the atmosphere by telegraph to the stations where the trains are formed, so that the trains may be regulated in accordance.

The last engines constructed by *Sigl*, have 1.830 square feet of heating surface, cylinders 18,90 inches by 24 inches, weigh 44 tons empty, and full 50 tons (tender not included), and draw 200 tons up one in 40.

The Semring line has lost much of its importance since the opening of the line from *Œdinburg* to *Nagy-Kanisa*, which permits the goods traffic between *Vienna* and *Trieste* to be directed along a line with very flat gradients, although less direct.

Line from Luxemburg to Spa, Verviers and Pepinster (Pl. CV, *fig.* 12) This line, 88 miles in length, has an exceedingly uneven trace, analogous to that of the line from *Forbach* to *Niederbronn*. Starting from *Luxemburg* at an altitude of 943 feet, it rises on the Ardennes plains by a succession of gradients of one in 80, one in 66,6, one in 50, to the altitude of 1.629 feet, redescends to 853 feet, to rise again by inclines of from one in 55 to one in 50, and then runs sharply down to *Spa*, by an incline of one in 40, and to *Pepinster* by one in 50. The radius of the curves goes as low as 273 yards.

According to M. *Vuillemin*, the loads drawn up the one in 40 by an engine with six wheels coupled, by two of the engines, by a locomotive with eight wheels coupled, and by the locomotive with working tender (399) are respectively :

120, 200, 180 and 200 tons.

But an important feature is omitted, the consumption.

In an experiment at which I was present in 1868, an engine with eight wheels coupled drew, up the one in 40, 200 tons at the speed of 6,21 miles an hour. The train was thus composed :

Train drawn	200 tons	
Engine..................................	44 »	
Tender..................................	20 »	(Water : 6 tons; fuel : 4 tons).
	264 tons	

The resistance in spite of so low a speed, may be estimated at 8 lbs. 8 on account of the curves. The effort of traction was thus

$$264\,(55{,}12 + 8{,}8) = 16.870 \text{ lbs} = 7{,}53 \text{ tons},$$

which brought the adhesion utilised, to $\frac{1}{5{,}8}$ of the weight. There must, certainly, be a very high value of the adhesion for an engine, to utilise its power at so low a speed as 6.21 miles an hour.

Santos, a Brazilian seaport (Island of *St. Vincent*) is joined to *San Paulo*, chief place of the province, by a railway which terminates at *Jundiahy*, and ought to be extended a little beyond so as to get one of the regions the most fertile in coffee (Pl. CIX, *figs.* 3 and 4).

At only 13,67 miles from *Santos*, rises the chain *Serra do mar* (407), which mounts abruptly up to a height of from 2.625 to 2.953 feet. The locomotive after running over this small section of 13,67 miles, on a gradient of one

in 77 and with curves of 372 yards, stops at *Mugi*, at the foot of the escarpment surmounted by a series of inclined planes, which we shall return to in Chapter XVI.

Let us note in passing that the river *Cubatao*, was passed by a masonry bridge, which was carried away by an enormous flood, carrying along with it masses of timber descending from the mountains. These mishaps are to be feared in countries where there is a want of exact data on the regimen of the water channels; the bridge in question has been replaced by an iron one.

On the plateau, the locomotive resumes its place; from the summit of the *Serra* to *San Paulo*, 30 miles, the inclination does not exceed one in 50, with 268 yards as minimum radius of curves; from *San Paulo* to *Jundiahy* (34 miles), there is a mile of one in 50, and minimum radius 372 yards.

The service is done by engines with four and six wheels coupled. A part of the latter, constructed by the *Avonside* Company, has eight wheels; the diameter of the six coupled is 4,0 feet; the leading ones, 2 ft, 75 in diameter, are provided with radial boxes, and the extreme coupled axles have a longitudinal play, regulated by *Caillet's* springs (332).

Total wheel base		16,73 feet
Rigid d°		11,00 feet
Cylinders	16,00 inches ×	24 inches stroke.

On account of the dryness, and the elevation of the adhesion, and in spite of the low speed, a little of the adherent weight was sacrificed without hesitation to the sharpness of the curves, and yet the tyres, although in steel, wear very rapidly.

Load drawn on one in 40, 130 tons at from 7,5 to 8 miles an hour; pressure in the boiler 133 lbs, 75 on the square inch.

Line from Vera Cruz to Mexico. Commenced before the disastrous expedition to Mexico, the execution of this line, although several times stopped is at last approaching completion. Its length is 233 miles not including 27 miles for the *Puebla* branch. It reaches the table land of *Mexico* at the altitude of 8.088 feet, with gradients which do not exceed one in 40. But the line is much less manageable on plan than in section. It appears that the radius of the curves goes down as low as 117 yards, and these exceedingly sharp curves are very numerous on a length of 20 miles. Thus it is not surprising that *Fairlie's* engines should have been adopted for this line. On such a trace, powerful engines, with great adhesion,

are only possible, on condition of being installed on two bogies. These in question have 1600 square feet of heating surface, and weigh full, 55 tons.

413. *Gradients of one in* 38,5 *and one in* 37. — The portion of the line from *Paris* to *Lyons*, comprised between *Amplepuis* and *Tarare* (Pl. CVIII, *figs.* 2 and 3) is one of the first examples, in France, of that necessity so often met with, even on the great lines, of admitting long and very steep gradients. In this case the incline is one in 38,5 on both sides, with curves of 437 yards radius. A tunnel nearly 2 miles long (*Tunnel du Sauvage*), almost entirely on one in 83,3, succeeds, on the northern slope to the long gradient of one in 38,5.

The normal velocity is fixed on this portion at 12,5 miles an hour for passengers, and 9,37 miles for the goods.

The gradient of *Aix-la-Chapelle*, on the Rhenish Railway, is one in 37, and 1,30 miles long. Worked at first by a stationary engine, it is on that account straight on plan; but it was not long ere the locomotive replaced the rope.

Among the gradients of one in 37, we will first take the *Lickey* incline on the *Birmingham* and *Gloucester* line of the Midland system. This incline, which is 2,14 miles long, was first worked by a stationary engine; but since 1840 (when *Norris* of *Philadelphia* supplied auxiliary engines for it), by locomotives only. It was thus at the time, a sort of wonder, almost entirely unknown in France however. Even in 1855, two engines, one 35 tons, the other 32, drew up it 240 tons at 6,46 miles an hour.

While the *Lickey* incline had been long worked by locomotives, the *Oldham* incline near *Manchester*, said to be also one in 27, was worked by a stationary engine until 1853 or 1854, when locomotives were applie d.

The Jura industrial line, from Neufchâtel to Chaux-de-Fonds and to Locle (Pl. XCIII, *figs.* 3 and 4). This line, a remarkable result of local initiative, starts from *Neufchâtel* at an altitude of 1.558 (147 feet above the lake), rises by one in 37 almost continuously up to the *Loges* tunnel, 2,05 miles long, at an altitude of 3.432 feet; descends into *Chaux-de-Fonds* by one in 37 (height 3.251 feet); crosses a second ridge at 3.333 feet and descends to *le Locle* at 3.097 feet. Midway on the line at *Rochefort*, is a reversing station (*rebroussement*) the only one in Europe.

Crossing of the Bhore and of the Thul Ghâts. (East Indies, 5,5 feet gauge).

The *Great Indian Peninsular* includes two main lines, both starting from

Bombay, forming however only one railway as far as *Kalian*, where one, the Southeastern division, branches off by *Poonah* towards *Madras;* and the other, the Northeastern division, goes by way of *Nasik* and *Bhusawal* to join at *Jubbulpoor*, the *Jubbulpoor* line of the East Indian Railway, the main line connecting *Calcutta* with *Delhi* and the *Punjab*.

They both cross the chain of the Ghâts, which skirt at a distance of from 25 to 30 miles the western coast of the Deccan, and separate *Bombay* from the rich territories of the interior.

The Ghâts are less a chain properly so called, than the border of an elevated table-land, as indeed their name, which means : quay, points out. It is, save the lesser altitude, and the existence of defiles by which a railway can rise up to the table-land, a similar thing to the Serra do Mar, in Brazil (409-412). The cuts by which the two divisions have made their way up, are the *Bhore Ghât* for the Southeastern, and the Thul Ghât for the Northeastern.

When the passage through the Thul Ghât was completed in 1865, the line had already been worked on each side of the pass, which was crossed by the traffic, the principal part being cotton, in bullock carts. The height surmounted is inconsiderable, only 970 feet; the altitude of the culminating point being 1.912 feet. The maximum gradient with one reversing place, is one in 37, for a length of 4 miles. On a total development of 9,5 miles, this crossing presents no less than 13 tunnels, 6 viaducts of from 50 to 200 feet in height, embankments of 88 ft, 5, cuttings of 60 feet; which explains the cost of £ 45.000 per mile. The sharpest curves have a radius of 375 yards.

At the *Bhore Ghât*, a height of 1.830 feet is attained in 15 miles, at a mean rate of one in 43,7; but the maximum is however one in 37. Short pieces of level and of one in 333 facilitate the working of the engine. The lowest radius is 330 yards.

This portion is not less studded with works than the preceding one. The Indian railways are however made with the same care and the same abundant solidity as the great European lines. To complain of English engineers, as has sometimes been done, not having followed in the footsteps of the Americans, is quite wrong. The conditions are altogether different. The population of India, which is so dense, assures a considerable enough traffic for the main trunk lines, to have rendered any niggardliness in their establishment quite unreasonable.

In 1867, four years afterwards, the working of the *Bhore Ghât* was interrupted by a grave accident: the entire fall of one of the principal works,

the *Mhow-kai-Nullah* masonry viaduct. This viaduct, on a gradient of one in 40, and on a curve of 490 yards, had for some time previously shown symptoms of destruction, when it suddenly went down in the middle of a violent storm.

To carry on the working of the line during the reconstruction of this work, in iron, a temporary line was laid, running down to the bottom of the valley, with gradients of one in 7,5 on one side, and one in 5,78 on the other, with curves of 220 yards, and one even of 110 yards radius. A locomotive and a fixed engine with a rope were employed concurrently to pass the waggons, two by two, over this deviation of 790 yards. Those ascending the Ghât, received a start from a locomotive, ran down the first slope and up the other as far as the point where they were taken by the rope. As to the waggons coming down the Ghât, all that had to be done for them, in that direction was only to complete their rise up one in 20; this was effected by a goods engine.

The service was thus carried on for eight months without the slightest accident.

Cerro de Pasco line (Peru). — This line, established in the heart of the Corderillas, serves the works in connection with the principal silver-mine in Peru, which has been in operation for three centuries; it has, like the preceding, one in 37 for ruling gradient, and rises as high as 14.210 feet.

Manning, Wardle and Co of *Leeds*, have constructed engines for this line, which should haul 80 tons up these gradients.

So long as the principal line (417) by which it will be connected to the coast of the Pacific is uncompleted, the only communication is by mules; which involves a double and serious charge on the construction: that is to say, taking down the engines in pieces light enough for a mule's load, and a very heavy amount of erection on the spot.

Crossing of the Jura by the Central Swiss line. — We have already cited the drawback of this crossing: the existence of a long tunnel on a gradient of one in 37. At the same time, in spite of a pretty active traffic, the difficulties of insufficient ventilation are not encountered. This is doubtless owing to natural circumstances, and to the steps taken to avoid slipping, steps among which should be reckoned, and even in the first rank, a moderate load for the engines.

Starting from *Olten* there are: level for 1,17 miles; one in 40 for 2,52 miles; 1,55 miles of tunnel on one in 37; a short piece of level at *Laufelfingen* 0,2 of a mile; then one in 48 down for 3,25 miles, and down for 0,86 of a mile, into the station of *Sissach*, on one in 57.

414. *Gradients of one in* 33,3. — *Section from Murat to Aurillac* (Pl. CVIII, *fig.* 1). — This difficult section offers a remarkable example of the diversity of traces which lines of railway in mountainous countries often admit of, and of the economy which very steep gradients can effect in the construction, but at the expense of the working.

"A first trace", says M. *Nordling* (*), "was tried by MM. *Garella* and *Domenget* with gradients of one in 62,5. It crossed the *Lioran* nearly at the existing altitude and quitted the valley of *La Cère* above *Thuzac*, to take into that of *La Jordanne*, wherein it described an immense zigzag above *Saint-Cirgues*. This line included no less than thirty three tunnels, out of which that of *Lioran* was 1,29 miles, and that of *Bancarel*, 1 mile long, etc. Against this proposed line, the *Orleans* Company brought forward another in 1862, with gradients of one in 33,3 effecting a reduction in length of 4,35 miles, and an economy of construction of £ 960.000. This line, from which the existing one varied but little, was only adopted after a third trial line had been run, with the intermediate gradient of one in 43,5."

A traffic considerable enough could not be reckoned upon, to warrant the increase of expenditure, which this reduction of the gradients would have involved. The line with gradients of one in 33,3 was thus adhered to, with some improvements in details.

Starting from the *Murat* station at an altitude of 2.964 ft,5, the line rises along the hill side with one in 33,3 for nearly 5,6 miles, only interrupted by a piece of horizontal 380 yards long, where a lie-by has been placed, so as to allow trains which are too heavy to be divided, at need. This gradient ends at the summit station of *Lioran*, at the altitude of 3.779 feet.

The *Lioran* tunnel, 2.141 yards long, is straight, and runs down towards *la Cère* with one in 41,7. Its approaches on this side have, in addition to the one in 33,3 of which there are upwards of 9 miles, curves of 328 yards radius, 39,3 per cent of the development of the section consisting of curves of this radius.

The line is worked, as we have seen (261), by engines with eight wheels coupled, which draw 126 tons at 7,46 miles an hour, and by tank-engines, with ten wheels coupled, which draw 160 tons (395), but using much more fuel.

Crossing of Mount Cenis, or more exactly of Mount Frejus (Pls. CVI and CVII). — The project as carried out, retains several of the essential features of M. *Maus's* project, and particularly the height of the entrance

(*) *Compte rendu statistique de la construction de la section de Murat à Vic-sur-Cère* (autograph).

to the tunnel on the Northern side; the axis of the tunnel has been brought parallel to itself Westwards, 0,62 of a mile, which simplified the line, and reduced the gradients on that side. The uniform inclination, through the tunnel of one in 52,6 proposed by M. *Maus*, and which would have been very troublesome with regard to the drainage of the works at the Southern end, especially in the case of abundance of water, has been broken up into a rising gradient of one in 45, from the Northern mouth to the middle, and thence a falling one of one in 2.000 to the Southern mouth, for running off the water.

The limit, one in 28,6 at first adopted for the Northern side, was able to be brought down to one in 33,3, by further trials. This is also the limit on the Southern side.

As to the curves, the radii do not go below 547 yards on the Italian side. The French side is not so well off; there are some of 437 yards, and even of 377 yards, but only in the sort of buckle the line forms in its development round *Modane*, and the gradient on them does not exceed one in 40.

The Eastern of France eight wheels coupled engines (259), employed temporarily between *St Michel* and *Modane*, draw, up these gradients of one in 33,3, 150 tons at 9,32 miles an hour, even in indifferently favourable weather. These engines are moreover, quite as powerful as those of the Méditerranée, series 2.501-2.530, for which the load-book admits at that speed, 180 tons (391); it is true however that the latter have a little more adhesion.

On the Italian side, the steepest gradients being concentrated on the lower half of the section, from *Bussoleno* to *Salbertrand*, the traction service had to be arranged accordingly. For example, a train of 180 tons starts from *Bussoleno*, drawn by two *Beugniot* engines, both in front. At *Salbertrand*, these are replaced by two sixwheeled engines; at *Bardonnecchia*, a sixwheeled engine is put on behind to get over the one in 33,3 for 547 yards only, which runs up to the tunnel mouth; and as soon as the train gets into the tunnel, this auxiliary engine leaves it.

It is difficult to understand why one of the engines is not put at the tail of the train on the long inclines of one in 33,3, and even on flatter ones. This is the less easy to comprehend, as the rule as to one engine behind is rigorously carried out on the *Giovi* incline, worked by the same company. It is true that the gradient in that case is still steeper, and that the company has besides only followed in the footsteps of the State, from which it took over the line from *Turin* to *Genoa*.

The load on the two types of engines in use on the Mount Cenis line, is regulated according to the following table:

TYPES OF ENGINES.	REGULATION LOADS from *Bussoleno to Modane.* at the speed of miles							REGULATION LOADS. from *Modane to Bussoleno* at the speed of miles					
	9	12	16	19	22	25	28	9	12	16	19	22	25
	From Bussoleno to Salbertrand. Maximum gradient one in. 33 Maximum down incline... 0,000							*From Modane to Bardonnècchia.* Maximum gradient 0,030 Max. down incline one in 33					
	tns	tns	tns	tns	tns	tns	tns	tns	tns	tns	tns	tns	tns
With 6 wheels coupled outside cylinders..	93	91	85	69	54	42	»	93	91	85	69	54	42
With 8 wheels coupled outside cylinders..	145	143	140	113	»	»	»	»	»	»	»	»	»
	From Salbertrand to Oulx. Maximum gradient one in. 62 Maximum down incline... 0,000							*From Bardonnècchia to Beaulard.* Maximum gradient 0,000 Max. down incline one in 38					
With 6 wheels coupled outside cylinders..	199	195	183	154	128	106	87	345 tons.					
	From Oulx to Beaulard. Maximum gradient one in. 56 Maximum down incline... 0,000							*From Beaulard to Oulx.* Maximum gradient 0,000 Max. down incline one in 56					
With 6 wheels coupled outside cylinders..	187	183	170	143	119	98	80	530 tons.					
	From Beaulard to Bardonnècchia. Maximum gradient one in. 32 Maximum down incline... 0,000							*From Oulx to Salbertrand.* Maximum gradient 0,000 Max. down incline one in 62					
With 6 wheels coupled outside cylinders..	113	111	104	86	69	55	»	560 tons.					
	From Bardonnècchia to Modane. Maximum gradient one in. 33 Maximum down incline.... 0,000							*From Salbertrand to Bussoleno.* Maximum gradient 0,000 Max. down incline one in 33					
With 6 wheels coupled outside cylinders..	93	91	85	69	54	42	»	300 tons.					

In the case of two engines to one train, the regulation load is obtained by subtracting 20 tons from the sum of the individual loads of the two engines. These loads apply in summer; for winter, that is to say from the 1st Nov. to the 1st April, they are decreased by $\frac{1}{10}$th.

415. *Method of determining the loads.* — It is to the point which we have now come to, that we put off (398) the examination of the mode of determi-

ning the loads of engines with six wheels coupled, series 805-100, which perform a great part, as we see, on the southern side of Mount Cenis.

Heating surface..	Fire box.....	80,40 sq. ft.	1344,10 sq. ft.	No of ats : 9 effective.
	Tubes.......	1.263,70 »		
Pistons..................		17,72 inches $\times$ 25,59	$\frac{d^2 l}{D} = 154,64$	
Wheels.......... diameter		4,33 feet		
Weight of engine filled....		34,00 tons	54 tons	
Weight of tender.........		20,00 »		

Production of steam; 12.346 lbs, per hour, or 9,22 lbs, per square foot of heating surface.

Value admitted for the absolute pressure during admission, at any degree of expansion: 105,82 lbs, on the square inch. We shall return to this figure.

The pound of saturated steam occupying at this pressure, a volume of 4,17 cubic feet, the bulk of steam to deliver per hour $= 51,473$ cubic feet. U being the variable volume of admission at each stroke, n the number of revolutions per hour, we have:

$$51,473 = 4n\mathrm{U}, \qquad n = \frac{12,868}{\mathrm{U}}.$$

The speed in miles an hour V is

$$\mathrm{V} = \frac{n\pi \times 4,33}{5280},$$

and replacing n by its value,

$$\mathrm{V} = \frac{33,15}{\mathrm{U}}.$$

We should have for the maximum admission of the steam, if it could take place during the whole of the stroke:

$$\mathrm{U} = 0,785 \times \overline{1,48}^2 \times 2,13 = 3,67 \text{ cubic feet.}$$

$$\mathrm{V} = \frac{33,15}{3,67} = 9,06 \text{ miles an hour.}$$

But with the maximum travel of the slide, the admission takes place only during 0,93 of the stroke. The speed should therefore be $9,06 \times \frac{93}{100} = 9,32$ miles an hour.

For a speed of 12,0 miles, the admission would be, in hundredths of the stroke: $0,93 \times \frac{9,32}{12,00} = 0,72$.

For 15 miles: $0,93 \times \frac{9,32}{15} = 0,58$, and so on.

This fixed, the effort of traction on the pistons will be obtained by estimating separately, on the side of the steam, the constant effort during admission, and the mean effort during expansion, and deducting from the sum of these, the mean effort of the back pressure on the other side. For the latter 18 lbs, 50 on the square inch has been admitted; the effort on the pistons, for an admission during the whole stroke, would thus be:

$$\frac{d^2l}{D}\,(74{,}40 - 13{,}00), \quad \text{or, as} \quad \frac{d^2l}{D} = 0{,}10,\ 6{,}14 \text{ tons.}$$

This becomes reduced to 5,92 tons, by cutting off at 0,93 of the stroke, and taking the expansion according to *Boyle's* law. Deducting 0,50 of a ton for the resistance of the parts, there remain 5,42 tons for the effort of traction available at the circumference of the wheels. Proceeding in the same way for the other proportions of cut-off, the following table is made out:

VELOCITY in miles an hour.	ADMISSION stroke of piston being unity.	EFFORT OF TRACTION measured on the pistons.	RESISTANCE of the machinery.	EFFORT OF TRACTION available at the wheels.
		tons.	tons.	tons.
9,32	0,9360	6,123	0,50	5,623
12,43	0,7020	5,735	0,50	5,235
15,53	0,5616	5,213	0,50	4,713
18,64	0,4680	4,717	0,50	4,217
21,75	0,4114	4,277	0,50	3,777
24,86	0,3510	3,893	0,50	3,393
27,97	0,3120	3,557	0,50	3,057

The adhesion calculated at $\frac{1}{7}$th of the weight being 4,857 tons, the two efforts of traction 5,623 tons, 5,235 tons, being greater than that figure, should be replaced thereby.

For example, if the load x is required, drawn on a level, at 9,32 miles an hour; it is the effort 4,857 tons which should be taken. Admitting for the resistance on a level, at this speed 7 lbs, we have:

$$x = \frac{4{,}857 \times 2240}{7} = 1.554 \text{ tons};$$

this is the gross weight of the train. Deducting the weight of the engine and tender, or 54 tons, there remain for the train that can be drawn, 1.500 tons.

In the same way to get the load for a gradient of one in 33,3, and at a speed of 25 miles an hour, the effort of traction and the resistance on a level being 3,393 tons, and 0,0054, we have:

$$x = \frac{3,393}{0,03 + 0,0054} = 95,80 \text{ tons},$$

and deducting the 54 tons of the engine and tender, 41,8 tons. It is in this way the values in the following table have been calculated:

Velocity in miles an hour		9,32	12,43	15,53	18,64	21,75	24,86
Effort available.........		4,857	4,857	4,713	4,217	3,777	3,393 tons
Resistance on a level....		0,0032	0,0036	0,0040	0,0044	0,0049	0,0054 fraction of a ton.
		tons.	tons.	tons.	tons.	tons.	tons.
Gradients one in....	0	1.463	1.296	1.124	904	717	574
	330	730	683	619	516	424	330
	200	539	511	470	395	328	272
	143	423	405	374	316	263	220
	111	345	332	309	261	218	182
	91	289	279	261	220	183	153
	77	247	239	224	188	157	130
	67	214	208	194	164	136	113
	59	187	183	170	143	119	98
	53	165	161	151	142	104	85
	48	148	144	134	112	92	75
	43	132	129	120	100	81	65
	40	119	117	108	90	72	57
	37	108	105	98	80	64	51
	34	97	95	89	72	57	45
	33	93	91	85	69	54	42
	32	88	87	81	65		
	31	85	84	77	62		
	30	81	80	73	59		
	29	77	76	70	56		
	28	74	73	67	53		

I had expressed to M. *Pelletier*, then locomotive engineer of the Upper Italy lines, some doubts as to the exactness of the figures in this table, which did not appear to me perhaps to make enough of the influence of the increase of the velocity on the decrease of the loads. In precise terms, it seemed to me scarcely probable, that an engine utilising the whole of its power in drawing, on a gradient of one in 33,3, 93 tons at 9,32 miles an hour, could really draw on the same incline, 42 tons at 25 miles an hour.

"The exactness of our loads at speeds from 9,32 to 18,64 miles an hour", M. *Pelletier* replied to me on the 29th of Oct. 1872, "has been verified by the service done by our engines since the opening of the line from *Bussoleno*

to *Modane*". The velocities on that section not exceeding 18,64 miles an hour, the exactness of the loads calculated for higher velocities had not been verified, and M. *Pelletier* was good enough to have a train made up of about 42 tons, running at 25 miles an hour, between *Bussoleno* and *Salberstrand*. The following are the notes of the trial, superintended by M. *Fescot* head of the drawing office at *Turin:*

Special train 510. — *Engine* 914.

1 waggon H*f* with iron frame.	— Tare....	6,25 tons.	— Load....	10,00 tons
1 waggon do. »	do. ...	6,20 »	»	10,00 »
1 waggon D*f* with wooden frame.	do. ...	5,10 »	»	»
1 waggon N »	do. ...	4,00 »	»	»
		41,55 tons		

Length of the trip of 14,91 miles, 38 minutes; to be deducted, one minute for a stoppage at *Chiomonte*, and 30 seconds for slackening and getting up steam again. This makes the velocity 25 miles an hour.

"The trial of yesterday", says M. *Pelletier*, "confirms the exactitude of the loads at 25 miles an hour."

The very terms of the report, which M. *Pelletier* was good enough to communicate to me, render it difficult to accept this conclusion. The engine of course did draw 42 tons at 25 miles an hour, but under what conditions?

"The pressure", says the Italian report, "kept up constantly to *nine* atmospheres effective" (that is to say at one atmosphere above the regulation pressure); "the *Giffard* injecter was open almost the whole time; the level of the water, high at the beginning of the trip, was rather low at the end. The fire was fed seven or eight times" (that is to say every 4 or 5 minutes).

All this shows very *forced* running. It is in the nature of things to exact a great deal of work from engines on steep gradients; but every thing indicates that the line was passed in this case, that the engine could not have kept that running up for long, that in fact it was not working under really practical conditions. The train was not to stop on the way, according to the report; the stoppage at *Chiomonte* was perhaps for doctoring the fire a little, which would back up the opinion that it is a question of an experiment of maximum, and not of normal traction.

According to the preceding bases, the work available per second, at the circumference of the driving wheels, would be:

at the velocity of 9,32 miles an hour, or 13,78 feel a second

$$(42,00 + 54,00)\ (0,030 + 0,0054) \times 13,78 = 67,25 \text{ foot tons,}$$

or 273 horse power,
and al the velocity of 25 miles, or 36,45 feet a second
$$(42 + 54)\ (0{,}030 + 0{,}0054) \times 36{,}45 = 123{,}87 \text{ foot tons,}$$

that is to say 504 horse power, or nearly 0,4 horse power per square foot of heating surface! And these quantities of work so different, would correspond to the same expenditure of steam, and of course cost the same!

A speed of 9,32 miles an hour is very reasonable, very sufficient indeed for goods trains, especially on such gradients. But we see that the type of engine in question would work at this speed, under very disadvantageous conditions; it would utilise very inefficiently the mechanical work which its boiler can produce; and thus either a higher speed is adopted, without utility in itself, or if this speed be required to be kept to, the load reduced so as to reduce the production; the fuel is thus better utilised, definitively, than in pushing the production to 9 or 10 lbs per foot of heating surface, because the expansion is effectively applied. Therein especially lies the explanation of this fact, already noticed (386), that the heating surface is in general much less efficiently utilised in goods than in passenger engines; it is quite simply because matters must be so arranged as to make use of the expansion.

Running without cutting off the steam or nearly so, as in the case of the Upper Italy engine (0,93 of the stroke), would be a heresy in mechanics; the steam is cut off between $\frac{1}{2}$ and $\frac{1}{3}$ of the stroke, unless at starting; and consequently, either a speed higher than 9,32 miles must be accepted, or a load inferior to 1.463 tons, for example, which corresponds thereto, on a level.

But are we really in this alternative, either to force the speed uselessly, which enhances the resistance, or to reduce the load which the engine can carry at the lower and sufficient speed? Certainly not.

The whole thing is to proportion the engines properly.

It is simply because their cylinders are very often too small to expend at a low speed and at the suitable degree of expansion, the steam which the boiler produces, that the step has been taken on most lines, deliberately, to reduce the production of the steam.

With cylinders large enough, a low speed can be adopted at the same time that the evaporation can be actively pushed on, and a high degree of expansion used, the *sine quâ non* of the economical employment of steam. The relatively considerable volume of the cylinders, on the *Méditerranée*

lines, has been a very lucky thing for the reform of the loads (386 and following).

As to the very essence of the method followed on the Upper Italy lines establishing the correlation of the loads and the speeds, it has the inevitable fault of dealing with elements imperfectly known. But of course in practice this has to be passed by, and approximations, often of the roughest, put up with, for want of better. Thus the pressure in the cylinders during admission, cannot, as is supposed, be the same for all degrees of expansion between limits so wide as 0,93 and 0,31 of the stroke. The hypothesis of the back-pressure being constant whatever may be the cut-off, is another error. But we cannot push this discussion any farther: to do so, would be to anticipate the study of the distribution of the steam (III, 139 and following, 374 and following). What precedes, will suffice however, to give an idea of the difficulties which the solution *a priori* presents, of the problem of the loads which engines can draw at different speeds.

416. *Gradient of one in* 31 *at Capvern* (line from *Bayonne* to *Toulouse*) (Pl. CVIII, *fig.* 4). — The line from *Bayonne* rises on the plateau of *Lannemezan*, which crowns a spur separating the valleys of *Luchon* and *Bagnères-de-Bigorre*. The inclinations of the two sides are very different from *Tournay* to *Capvern*, one in 31 for 5,77 miles, then one in 32 for 0,72 of a mile, while towards *Montréjeau* the limit is one in 62,5; in about 6,83 miles the line rises 1.069 feet. All the trains are hauled by simple engines with six wheels coupled (4 ft, 92 in diameter) always two to a train, one of them being behind. They thus draw normally, half a score of passenger carriages, and from twelve to sixteen goods waggons. It results from the section of the line that the work of the auxiliary engines is confined to the portion between *Tournay* and *Capvern*.

Gradients of one in 30,3. As far back as 1841, light locomotives had drawn loads proportional to their power on the inclined plane from *Erkrath* to *Hochdahl* (*Düsseldorf* and *Elberfeld* line), the rate of inclination of which is one in 30,3, and the length 1,52 miles. But we need not dwell on this incline which, at first worked by stationary engine (*), is now so by a cable drawn by a locomotive descending the other side, utilising thus its power

(*) *Handbuch für specielle Eisenbahn Technik,* vol. I, page 701. This work is doubtless better informed on the subject of the German line, than on that of the *Cowlairs* incline, stated in the same article, (page 700), as worked by locomotives. (*Author's note.*)

and, its weight : a compound method for which there seem bare grounds, and to which we shall come back presently.

New South Wales line. — The *Great Western* line of New South Wales was opened a few years since, from *Sidney* as far as the foot of the Blue Mountains, which separate the coast from the rich plains of the interior. This chain is crossed, at an altitude of 3.760 feet, by gradients which rise progressively from one in 62,5 at first, up to one in 30,3, with curves as low as 176 yards. But it is especially on the northern slope, in the valley of *Lithgow*, that the difficulties are accumulated. On a development of 3,0 miles, the line forms a series of zigzags, which are almost one on top of the other, and gaining 490 feet with a mean rate of one in 31.

There are other examples of one in 30,3, but of short lengths and at the ends of lines. Such is the incline of three quarters of a mile on the branch which joins *Folkestone* with the main line between *London* and *Dover*.

417. *Gradients of one in 28,6. Line from Genoa to Turin. Crossing of the Apennines.* This line met with serious difficulties in the passage of the Apennines. On the Northern side, in the valley of the Scrivia, the rate of inclination was able to be limited to one in 100. But the escarpment of the Southern side, and the almost absolute impossibility of developing in the narrow valley of the *Polcevera* led to very different rates. The limit might have been lowered, by giving up this direction for the line, the straightest one, indeed too straight; but do what they might, only gradients were to be got which were altogether unheard of at that date. Doubts arose, from want of precedent, as to the work that could be got out of the locomotive on such gradients; and the condition was decided on, of laying out the line so as eventually to suit working by a stationary engine and rope; a last resource, which could only be carried out by rendering the line more difficult for locomotives. But if it is easy now-a-days, with all the facts acquired, to condemn this, the measure was when taken, certainly a prudent one. There was besides some leaning in favour of the stationary engine, through a particular circumstance. The small water-courses which run down the Southern flank of the Apennines, offered but insignificant resources for the supply of the city of *Genoa;* but the difficulties were removed by the cutting through of the railway tunnel, on the Northern slope which opens into the valley of the Scrivia. The city obtained a concession of 70 gallons a second, taken from that torrent, and this supply, conducted by the Giovi tunnel into the valley of the Polcevera,

insured in every weather an amount of work $= 771{,}6 \text{lbs} \times 951$ feet, or 1.300 horse power, not by any means to be despised, above all at a period when the price of coal at *Genoa* was much higher than at present.

With this consideration was connected a vague hope of the application of compressed air as a means of traction.

M. *Sommeiller* commenced, at *Sampier d'Arena*, the researches which were later to bring about quite a different result, and one of quite another bearing: the creation of a rapid method for the execution of long tunnels attacked only at the two ends. The application of compressed air to traction on the Giovi incline was even admitted in principle by Count *Cavour*, to whom new ideas were always congenial, and in whom M. *Sommellier* inspired deserved confidence. Supplies were voted, and an agreement, sanctioned by a law, was entered into between the State and MM. *Sommeiller*, *Grandis*, and *Grattoni*. But it was premature; it discounted a progress which was not realised until later, by the invention of the column of water compressor, and especially of the hydraulic piston compressor; and the question was soon brought back, at Giovi, to its two primitive terms: locomotive, or stationary engine and rope.

The last touch was being given to the construction of the line towards the end of 1853, that is to say the period when, on their side, the Austrian engineers had just completed the Semring. It was no more known at *Turin* than at *Vienna*, how the traction would be done; and even while in Austria the uncertainty was only as to some of the details of construction of the locomotive, the trace necessitating its adoption, the principle even of the mode of traction was still in question in Italy.

The Piedmontese engineers were thus following the Semring experiments, with an interest easy to conceive. The competing engines barely satisfied them, any more than M. *Engerth's* did. They complained, not of the makers, who were bound by the conditions of the program, but of that program itself, for having gratuitously enhanced the difficulties of execution, of driving and of maintenance, by imposing the unity of the evaporating apparatus; and they judged it much simpler to extend to the boiler, the separation into two parts applied to the motor-apparatus, driven at the same time as one engine. Thus was fallen upon the coupling together of two engines back to back. *Robert Stephenson*, consulted on the subject, approved of the arrangement.

Leaving the *Busalla* station, culminating point at the low altitude of 1.184 feet, the line goes into tunnel (the *Giovi*) for a length of 2 miles, down a continued one in 35, with two curves, and at the summit of 437 yards

radius, for 440 yards radius, and 330 yards length, the other in the middle, 1.100 yards radius. To the tunnel succeed inclines down, of one in 28,6 for 1,55 miles, one in 35,6 for 0,70 of a mile, and one in 48 for 1,86 miles, as far as *Pontedecimo*. From this point, the rates of inclination go down to one in 90,9 and below. But between *Pontedecimo* and *Busalla*, that is to say on a development of 6,05 miles, the height gained is 862 feet.

The first engines, with four 3 ft, 5 driving-wheels, with 776,64 square feet of heating surface, cylinders 14 × 22 inches, and carrying 3 tons of water in a reservoir installed on the boiler, weighed 27 tons, which was evidently excessive for two pairs of wheels. Two of these engines, 54 tons, hauled, full load : 70 tons at passenger speed, 15.53 miles an hour; and from 90 to 96 tons at goods' speed, 10 miles an hour. Sometimes from the state of the rails, this load was reduced to 80 tons. Consumption of goods trains on the ascent, 128 lbs per mile, or 64 lbs each engine. These engines are broken up, as their boilers become unfit for service, and they will not be long in completely disappearing.

The twin-engines with six wheels, one weighing 34 tns, 80, wear the road and the tyres far less. The pair does the same work as the *Beugniot* engine, but with greater consumption of fuel. For several years the *Giovi* incline has been worked by these twin-engines, and by the new eight-wheeled engines of M. *Beugniot* (outside cylinders, Nos 1.001 to 1.021) weighing full and with tender, 69 tons, 51 of which are coupled.

The ordinary engine, with six wheels coupled, and separate tender, only run accidentally on this section.

An engine of the series 1.001 to 1.021 draws 120 tons at 15,53 miles; two engines draw actually a little less than double, or 220 tons. These loads apply to the fine season. I saw in January 1872, two *Beugniot* engines coupled to a train of 180 tons, one in front and the other behind, which had quite enough to do.

The mixed trains are frequently drawn by a *Beugniot* engine in front and a pair of twin-engines behind. The composition and condition of running of such a train, follow :

8 passenger carriages and 10 goods waggons		164 tons
1 *Beugniot* engine	69	123
2 Twin engines (four wheels)	54	
Gross weight		287 tons

Admitting for the resistance on a level 6,6 lbs per ton, the effort to transmit by means of the adhesion on the incline of one in 28,6, was:

$$\frac{287 \times 83,78}{2240} = 10,73 \text{ tons, or } \frac{1}{10} \text{ th of the adherent weight } 51 + 54 = 105 \text{ tons.}$$

The weather was misty, the leading engine slipped very much, the steam blowing off at 135 lbs. It was necessary to give sand almost constantly to stop this slipping, from which the hind engine was free, being more favourably placed.

In fine, the limit was reached, and 123 tons drew up 164.

The load of the four types of engines at the different velocities, is regulated as shown by the following table. Of course the figures refer, even in the case of the twin-engines, to a single engine.

TYPES OF ENGINE.	CERTIFIED PRESSURE.	LOAD DRAWN AT THE SPEED OF			
		9	12	15	19 miles
	ton	ton	ton	ton	ton
Tank engine with 4 wheels coupled.	8	50	44	37	30
Tank engine with 6 wheels coupled.	8	62	58	52	44
Beugniot engine with 8 wheels coupled (1001 to 1020)........	9	130	127	119	95
Engine with separate tender and 6 wheels coupled (805 to 1000)...	9	83	87	67	53

The necessity of providing against the breakages of couplings was comprehended from the outset. For direct passenger trains, when one engine is sufficient, it is put on in front. These trains are short, the breakage of a coupling little likely, and its consequences little to fear. But all the mixed or goods trains have an engine behind; and the rule is so absolute, that when a single engine is enough, there is none put in front; the train is entirely pushed, and without any running off the line, thanks to the moderate sharpness of the curves: minimum radius, 437 yards.

Incline of St. Germain-en-Laye. — There is at the gates of *Paris*, an incline of one in 28,6, long worked by locomotives; it is that of the old atmospheric line from *le Vesinet* to *St. Germains* (Pl. XCII, *fig.* 5). But on account of its shortness, only 0,62 of a mile, and its position at the upper end of the line, this incline has nothing in common with those on which a uniform speed has to be maintained.

The *Hercules*, with six wheels coupled 3,94 feet in diameter, cylinders 14,96 × 23,62 inches, weighing full 22 tons, drew with its tender of 10 tons, a load of 26 tons, which it could even start on the incline of one in 28,6.

Tank engines are naturally indicated for this short section with a very steep gradient. These engines (Pl. XLIII, XLIV, and XLV) have six wheels coupled, 4 ft, 25 in diameter, the driving axle behind (248) and consequently a long connecting rod *b*, *b*, a heating surface of 904,42 square feet, cylinders 16,54 × 23,62 inches, overhanging fire-box, frame inside, and outside cylinders. They weigh empty 27 tons, full 33 tons, uniformly distributed. A water-tank B, B (Pl. XLIV and XLV, *fig.* 1) fixed under the boiler to the longitudinals and two coal spaces at B, B (Pl. XLIV and XLV, *fig.* 2) take the supplies for six double journeys between *le Vesinet* and *St. Germain*. Load drawn, twelve carriages, or about 100 tons.

418. *Gradients of one in* 27. — The *St. John's Wood* branch of the *London* Metropolitan, a little line of 3,75 miles, goes off with one in 90,9, one in 45,4, one in 58,8, and at the end, one in 27. The line is worked by the tank engines already cited (332,4) with six wheels coupled 4,0 feet in diameter, cylinders 19,68 × 24 inches, weighing 45 tons, and drawing three great Metropolitan carriages, each weighing 14 tons empty and 18 tons full. On one in 27, the adhesion utilised is $(45 + 54)\ 0,0374 = 4,03$ tons, or less than one-tenth of the adherent weight.

For an absolute pressure in the boiler of 8 atmospheres, and consequently an effective pressure of $117,58 \text{ lbs} \times 0,65 = 73,43 \text{ lbs}$ per square inch on the pistons, the effort of traction referred to the pistons is $73,43 \text{ lbs} \times \frac{\overline{19,68}^2 \times 24}{4 \times 12 \times 2.240} = 6,50$ tons, which leaves a large margin 2 tns, 44 for the resistance of the machinery and the effort required for acceleration; a margin necessary in this case, for the trains have to be started on one in 27. Besides, during the period of acceleration, the lower speed and the longer admission raise the mean effective pressure on the pistons.

Mauritius lines.—This island possesses two small lines, one 30 miles long, the other 34 miles, on the ordinary 4 ft, 70 gauge. The first, the Northern Railway, has neither steep gradients nor heavy works. The second, the Midland Railway, crosses the mountainous region; the gradients thereon reach one in 27; its two extremities are on the same level: 20 feet above the sea, and it rises to an altitude of 1.821 feet. The gradients of one in 27 have a total length of 2,56 miles, and the longest one of them 1,16 miles.

The radius of the curves is generally above 2.000 yards, but sometimes goes down as low as 300 yards; and reverse curves are often joined without any tangent.

The first engines were tank-engines with six wheels coupled 3 ft, 5 in diameter, with 14,92 wheel base, cylinders $15{,}75 \times 21{,}65$ inches, weighing full, 27 tons. *Sir John Hawkshaw*, the consulting engineer, replaced these by tank-engines with eight wheels coupled, 4 feet in diameter, having the hind axle under the fire box, which allowed nearly the same wheel base to be got (15 ft, 42); cylinders $17{,}5 \times 26{,}75$ inches; weight with tanks full; 48 tons; mean weight 45 tons.

All the wheels have flanges, but the two intermediate axles, one of which drives, are alone fixed; the two end ones have a longitudinal play of 0,71 of an inch and the cranks pins have spherical bearings. Each wheel has its own sand tube.

The luggage-vans also are provided with sand-boxes, which allows the energy of the brake of that vehicle to be augmented. All vehicles with a brake should be provided in the same way on steep gradients.

These engines can draw up one in 17, 120 tons at 8,69 miles an hour. Their adhesion utilised is $(120 + 45) \times 40 = 6{,}60$ tons, or $\frac{1}{6{,}8}$ of the mean adherent weight. But to exercise this effort, the mean effective pressure on the pistons must reach 7 atmospheres; the corresponding effort, is, effectively, 7 tns, 345, a figure higher than 6 tns, 90 by 0,745 of a ton, which at 35,27 lbs per ton for the resistance of the machinery, gives 0,72 of a ton.

The effective work is 6,60 tons $\times$ 13,12 feet $=$ 86,59 tons feet or 352 horse power; but we cannot refer this figure to the heating surface, as that is not given.

Several years' experience has led the engineers of the Mauritius line to this result, which indeed comes out everywhere from a discussion of the facts : that for long gradients, one in 27 is excessive; that it is very desirable not to exceed one in 40; and to arrive thereat, there should be no hesitation at admitting a considerable increase in the cost of construction.

419. *Gradients of one in* 25. — The *Hartlepool* line near *Durham*, has gradients of one in 35,7, one in 33,3, and even one in 25, but for a very short length.

The line from *Mollendo* to *Pun* (Peru) a town on the banks of the great lake *Titicaca*, is worked for a length of 120 miles, as far as *Arequipa*, at the altitude of 7.454 feet. It presents especially on the first, the greatest dif-

ficulties of laying out, gradients of from one in 33,3 to one in 25, combined with continual and very steep curves.

The *Iquique* line (Peru), opened for working in 1872, for a length of 34,80 miles, connects the port of *Iquique* with the important nitrate of soda depots at *Nona;* it is remarkable by a gradient of one in 25 (*) for 11 miles, and by curves of 66 yards radius.

The *Fairlie* engines, constructed for this line by the *Avonside* works at *Bristol*, have to draw up that incline 150 tons at a speed of about 11 miles an hour, say 15 feet a second. These are the engines cited farther back (362), with four cylinders 15×22 inches, installed on two trucks with six wheels, 3 ft, 50 in diameter, and weighing 60 tons.

Gravity : engine and train..............................	210,00 tons $\times$ 0,04 = 8,40 tons
Resistance at 8 lbs, 8 per ton..	0,84 »
	9,24 tons

Which corresponds, on the pistons, to an effort $t = 9{,}80$ tons at least, and consequently to a mean effective pressure $p = \frac{tD}{2d^2l}$ (dividing by 2 on account of the four cylinders) = 91 lbs on the square inch, and in the boiler, an absolute pressure of about $10\frac{1}{2}$ atmospheres.

Effective work $9{,}24 \times 15 \times 4{,}07 = 564$ horse power, or 0,52 h. p. per square foot of heating surface (1.622 square feet).

The project ef connecting, by a railway, the town of *Lima* to the plateau comprised between the eastern and western branches of the Corderillas dates back to 1862. Brazil having opened up the navigation of the Amazon river to all flags, the Peruvian government went into the question of establishing a communication between the two oceans by means of that river, its tributaries immediate and secondary, and by a railway crossing the Andes. The line in course of construction from *Lima* to *Oroya* (about 102,5 miles) is the first instalment of that great joint line of communication (**); it is proposed to extend the line to the Chanchamayo, on which would be placed, at a point still undetermined, the commencement of the navigation.

Lima is at 499 feet and *Oroya* at 12.401 feet, but the crest of the western Corderillas should be passed, according to M. *Roy*, by a tunnel 2,5 to 2,75 miles long, at an altitude of 15.420 feet, and the line proposed along the valley of the Rimac, would not only include gradients of one in 25, but also numerous shunts, and the minimum radius of the curves, fixed in the

(*) Some documents give this gradient as one in 26,3.

(**) There is an interesting article in the *Annuaire des anciens élèves des écoles d'arts et métiers*, by M. *E. Roy*, commissioned in 1864 to explore the Peruvian Andes.

preliminary contract at 220 yards, would be reduced to 66 yards. But according to more recent information from an English source, these conditions seem to have been improved; the shunts would be avoided, and the minimum radius of the curves raised again to the original figure of 220 yards.

The steepest gradient of the French railways is that of the little branch from *Enghien* to *Montmorency*, one in 22; but is it only 0,75 of a mile long, and the velocity acquired is very well utilised on account of its position at the end of this little line.

" Locomotives of 30 tons," says M. *J. Morandière*, " draw thereon trains of eight carriages weighing from 80 to 90 tons, or three times the weight of the engine."

A gradient of one in 20,8 is stated to be on the line from *Jackson*, capital of Mississipi State, to *Vicksburg*, but we have been unable to find any detail as to its length, or the conditions of its working.

420. *Gradients of one in* 20 *and one in* 16,66. *Crossing of the Blue Mountains* (*Eastern chain Alleghanies*, *Central railway of Virginia*, *from Richmond to Ohio*). (*) — The execution of the summit tunnel being adjourned, Mr. *Ellet* proposed, in 1853, to carry out a temporary passage, crossing the neck, very narrow, at the altitude of 1.886 feet.

On the western slope, a length of 2,0 miles gained a height of 449 feet; mean rate of inclination, one in 28,3; maximum, one in 17,8.

The radius of the curves was 100 yards, and the rate of inclination thereon was one in 22. It was endeavoured so to arrange the gradients, as to compensate by a reduction of inclination, for the influence of the curves on the resistance. But that was necessarily conjectural. There was nothing to go upon; and it would be little better at the present day. It was soon found that the difference of one in 90 $\left(\frac{1}{17,8}-\frac{1}{22}\right)$, was not sufficient to realise uniformity of resistance. Every thing else the same besides, the speed was rapidly brought down in passing from a straight line on one in 17,8, onto a curve of 100 yards on one in 22.

It was then that Mr. *Ellet* had the idea of slightly lubricating the flanges of the wheels by means of a sponge dipped in oil, and which was applied at need against the flanges. It appears that uniformity of resistance was thus ob-

(*) See the pamphlet : *A description of the Railroad across the Blue Ridge at Rock fish gap.* By *Ch. Ellet*; Philadelphia, *Collins*, 1856.

tained, without interfering with the adhesion, the tyres and the rolling surface of the rails not being touched by the oil.

Eastern Slope. It is on this side that the greatest difficulties were met with: development, 2,37 miles; height gained, 610 feet; mean rate of inclination, one in 20,4; maximum gradient, one in 17,8 for 875 yards. The limit radius for the curves was also to have been 100 yards, but in execution one curve of 78 yards was obliged to be adopted, towards the middle, on a gradient of one in 23. The line was worked by engines with six wheels coupled, 3 ft, 5 in diameter, with cylinders $16{,}50 \times 20$ inches, driving axle behind, and weighing full 25 tons.

The wheels were exceedingly close together, so that the length of the wheel base was only 9 ft, 25.

In order to better adapt the engines for running on curves, the leading and middle axles were connected by a special frame taking the load from the principal frame by jointed supports. The axle boxes worked in guard plates with cylindrical guides, in such a manner that the two axles formed an articulated parallelogram, yielding within considerable limits. This is the arrangement first applied by *Baldwin*, then imitated by M. *Beugniot*, and afterwards simplified by him by means of simply compensating beams combined with longitudinal play in the journals (332, 5° and 6°).

A third engine with eight wheels by Mr. *Anderson* of *Richmond*, was kept by for reserve purposes, on account of its greater stiffness on the curves.

Passenger trains: An eightwheeled luggage van, two carriages with eight wheels.

Goods trains : Three eightwheeled waggons loaded, or four empty, or uncompletely loaded.

The three loaded waggons weighed 43 tons; at times the load attained 50 tons.

Velocity: on the ascent 7,46 miles an hour; on the descent 6,20 miles at the most. Either more speed could have been obtained, or more load, but Mr *Ellet* desired a perfectly regular service, and not *feats*.

In the course of the working, a water column was set up on the Western slope, on one in 18,9; all the trains stopped there to take water, and started easily afterwards.

The train was, of course, held on by brakes. Every vehicle had one, acting on all the wheels, as well as a sand-box; further, strong chains going from the engine to the hind waggon, prevented any running backwards, in case of a coupling breaking. Two brakes were sufficient to hold on the two

waggons and the engine; but the driver had an air-brake in addition, which completed the safety precautions.

Mr *Lloyd* mentioned, at a meeting of the Institution of Civil Engineers of *London* (*), a mineral railway constructed in 1861, and ending at the port of *Pomaron* (Portugal). This little line, on a 3,50 gauge, and 12,43 miles long, has gradients of from one in 47,6, to one in 27,3, for a length of 8 miles, and one in 18,8 for 0,75 of a mile; the radius of the curves goes down as low as 55 yards. The line is worked by tank-engines with four wheels coupled of 2 ft, 23 diameter, cylinders 10 inches × 15 inches, weighing 12 tons and working at 8 atmospheres. They draw on one in 18,8, 26 tons at 5 miles an hour.

The adhesion utilised is thus admitting for resistance $\frac{1}{250}$,

$$(12{,}30 + 26{,}00)\,(0{,}053 + 0{,}004) = 2{,}18 \text{ tons, or } \frac{1}{5{,}6}$$

of the adherent weight. It is very probable, however, that the one in 18,8 is run up with the aid of the acquired velocity.

The town of *Pittsburg* (California) is connected with the *Somerville* mines by a little line of 5,34 miles which rises 775 feet; mean rate of inclination, one in 37; but it goes one in 18,5 for 1,90 miles; the curves are very numerous and very sharp.

Booth and Co., of *San Francisco* (344), have constructed for this small line tank-engines with six wheels coupled:

Heating surface...........	Fire box..........	69,96 sq. ft.	420,87 sq. ft
	Tubes............	350,91 »	

Cylinders : 13,75 inches × 18,00 inches.
Wheels : diam. 2,98 feet; wheel base : 9,51 feet.
(The middle wheels have no flanges).

Weight full : 20,30 tons.

The heating surface seems relatively very small, but as the tubes are very short, only 7 feet, the evaporative power should be considerable. Although favourable to the production per unit of surface, this proportion is not so to the economy of fuel. But it is warranted on steep gradients, where relative lightness is the main consideration, provided, of course, that the conditions as to adhesion are satisfied.

(*) *Minutes of Proceed ngs.*, vol. XXX (1870), page 67.

This engine drew, in a trial up the one in 18,5, 15 waggons weighing 30,90 tons at a speed of 11,81 miles an hour = 17 ft,22 a second.

Effort of traction measured on the driving wheels:

$$(20{,}30 + 30{,}90)\ (0{,}054 + 0{,}006) = 3\text{ tns},072, \text{ or } \frac{1}{6{,}5} \text{ of the weight.}$$

The high coefficient adopted 13 lbs, 23 per ton (0,006), is on account of the stiffness of the curves.

Effective work per second:

$$3{,}072 \times 17{,}22 = 52{,}90 \text{ foot tons} = 215{,}3 \text{ horse power.}$$

or over 0,5 h. p. per square foot of heating surface: a very considerable figure, even taking into account the efficiency of the tubes, and supposing the evaporation pushed very actively. It is very probable that the gradient of one in 18,5 was run up, not with a uniform motion, but by profiting by the speed acquired.

Line of Dom Pedro II (Brazil). The temporary crossing of the *Serra do Mar*, which allowed, as we have seen (204 and 409), the line to be worked before the tunnel of 2.625 yards was cut, had short gradients of one in 17,8, a longer one of one in 18,9, and curves as low as 83 yards. The line was regularly worked by *Baldwin's* engines, some with six wheels coupled, with fourwheeled *Bissel's* truck, the others with eight wheels coupled, having only a longitudinal play in the two first axles.

These latter, already mentioned (204) with wheels 3 ft, 57 in diameter, wheel base 16 ft, 40, cylinders 19 inches × 20 inches stroke, weighed full 28 tns, 5; according to the contract, they were to haul 80 tons at 8 miles an hour; but in reality, the velocity scarcely exceeded the half of this on the steepest gradients.

The effort of traction presupposes, as we have already said (204), a singularly favourable adhesion, about $\frac{1}{4}$.

This effort measured on the pistons, that is to say increased by the resistance of the machinery, amounts to about 7 tons. The mean effective pressure on the pistons : $p = \frac{tD}{d^2 l}$ is thus, making $t = 7{,}00$ tons, $D = 3$ ft,57, $d = 19{,}00$ inches, and $l = 20$ inches, $p = 92$ lbs, 96 on the square inch, which supposes an absolute pressure in the boiler of nearly 10 atmospheres.

The sharpest curves, of 83 yards radius, do not probably coincide with

the steepest gradients. If such a coincidence took place, the engines would doubtless not have been able to do the work stated.

Adhesion never fails, even in winter; but they also have recourse to sand.

On this line, as on that from *Santiago* to *Valparaiso*, and on others, the resistance on the curves is diminished by directing small jets of water on the inside face of the head of the rails; which reduces the griping of the flanges.

As we have seen on the subject of adhesion (200), the rail must be only moist, and not wet, for then nothing would be gained. At the same time, even if an excess of water were employed, a vertical surface would retain no more than enough to keep it moistened.

This use of water seems better than that of oil (418) which it seems difficult to apply to the flanges without the adhesion suffering.

421. *Gradients of one in* 16,7 *and above.* — The *Madison* incline (Indiana State) on the line from *Jefferson* to *Indianopolis*. Leaving the town of *Madison*, the station of which is on the banks of the *Ohio*, the line first follows the river for about half-a-mile, then turns northwards, rising for 1,25 miles on one in 16,7.

Worked at first by horses, it was not long before this incline received locomotives with six wheels coupled, weighing full 26 tons, with a separate tender of 16 tons, and which drew at most three waggons, or 33 tons and a half, figures to which corresponds an effort of traction on the wheels of 4 tns,756, and adhesion of $\frac{1}{5,4}$. 42 tons drew thus 33,5. About 1850, *Baldwin* constructed for this incline two tank-engines with eight wheels coupled, worked by two inclined cylinders, and provided as well with a pair of vertical cylinders driving a shaft with a toothed wheel, which could be lowered when required, and geared into a central rack (*Cathcart's* system). These engines, with 1.173 square feet of heating surface, and weighing in all about 50 tons, drew up the one in 16,7, 187 tons at a speed a little below 3 miles an hour; the total effort of traction was thus

$$(187 + 50)\ (0,06 + 0,003) = 14,93 \text{ tons},$$

and the work per second $14,93 \times 4,6 = 68,63$ foot tons, or 279 horse power, that is 0,24 h. p. per square foot of heating surface.

The frequent breaking of the teeth, particularly of the rack, which was in

cast-iron, determined the engineers to give up that contrivance and to return to simple adhesion.

In 1868, M. *Reubenwels* had a tank-engine with ten wheels coupled, made for this service (Pl. LXXIX, *fig.* 3) cited farther back (261).

Heating surface..	Fire-box....................	116,0	1.379,7 sq. ft.
	Tubes (201, 2 inches ext. diam).	1.263,7	
Length over buffers..			30,00 feet
External diameter of boiler....................................			4,66 »
Wheel-base..			34,12 »

The load drawn consists of a passenger carriage 49 feet long and of a luggage van of the same dimensions, that is to say a mean weight of 41 tons, at the velocity of 12,43 miles an hour, or of six goods waggons weighing 104 tons, at the speed of 5 miles an hour, there being no grounds for so low a speed as 3 miles an hour, as the effort of traction is transmitted solely by the adhesion. Already, with the load corresponding to the speed of 5 miles an hour, the adhesion utilised amounts to $\frac{1}{5}$ of the weight.

Work: effort of traction $(104 + 49)(0{,}060 + 0{,}003) = 9$ tns, 639; at the speed of 7 ft, 28 a second, the work is 70,17 foot tons = 285 horse power, or 0,20 h. p. per square foot of heating surface.

When the rails are moist from dew, or commencement of rain, sand must be made use of, if the pressure in the boiler exceeds 128 lbs on the inch, and if the regulator is full open. But even then the slipping is only accidental.

Mr *H. Latrobe*, engineer of the *Baltimore* and *Ohio* line, seems to have been the first to execute temporary lines crossing the ridges in the open, with very steep inclines, so as thus to utilise the portions of the line completed, while the tunnels were being completed. One of these crossings, that of the *Board Tree* tunnel (Alleghanies), had gradients of one in 17,8 to one in 15,6 for 2,33 miles, with curves of 120 yards minimum, and 133 yards mean radius. This crossing had eight shunts, five on one slope, and three on the other, each with a small portion of horizontal to start on. Locomotives with eight coupled wheels, of 24 tons and tender separate, drew 37 tons, tender included; the adhesion was kept, in all weathers, it is said, to $\frac{1}{6}$, by the use of very pure sand. There also, in order to diminish the resistance on the curves, the inside edge of the head of the rails was slightly oiled, which seems a surer way than the direct application of oil to the flanges of the wheels, as was done by Mr. *Ellet* at the crossing of the Blue Mountains (418).

Gradient of one in 14,9. The line from *Philadelphia* to *Columbia* has one

in 14,9 for three quarters of a mile. A small American engine by *Norris*, weighing in working train 10 tns, 3, and having only 7 tons on the coupled wheels, draws 17 tons up it, at a speed of 10,56 miles an hour. The coefficient of adhesion would thus exceed $\frac{27 \times 0{,}067}{7} = \frac{1}{3{,}8}$; but so short an incline may be very well run over at a decreasing speed, and there is no doubt that this one is so.

Gradient of one in 13,3. The example has often been quoted in France, of the little lines of the sugar-works of *Tavaux-Pontsericourt* (Aisne). They deserve indeed to be mentioned, provided that exaggerated results are not deduced therefrom. The deteriorated state of the parish roads decided two well known engineers, MM. *Molinos* and *Pronnier*, to supplement these by establishing on the very side of these roads, rails with locomotives. One of these little lines, from *Tavaux* to *Moranzi*, 4,6 miles long, has no excessive gradients, but curves of from 32 to 49 yards are numerous on it. The gauge of the line is one metre (3 ft, 28).

The other line, from *Tavaux* to *Gronard*, 5,28 miles long, presents in the first place a succession of gradients of from one in 66,6 to one in 40; then it crosses a ridge by gradients of :

One in 13,3 for 328 yards,
One in 17,0 for 328 yards,
One in 32,0 for 437 yards,

and on the other slope, the rate of inclination varies from one in 19 to one in 16,6 for 0,62 of a mile, with a curve of 55 yards radius. The traction is done by small tank-engines from the *Creuzot*, *Blanzy's* type, with heating surface of 212 square feet (fire-box 25 feet, tubes 187 feet), weighing empty 5,70, and full 7 tns, 50. One of these engines draws up the one in 16,6, at 9,32 miles an hour, in the worst weathers, one waggon weighing 7 tns, 50, and the double under favourable atmospheric conditions; which corresponds to an amount of adhesion utilised of $\frac{1}{7{,}6}$ in the first case, and $\frac{1}{5}$ in the second.

On the gradient of one in 13, the same engine draws always 7 tns, 50, and often 9 tns, 70; adhesion utilised : $\frac{1}{6}$ in the one case, and $\frac{1}{5{,}4}$ in the other, supposing this short incline to be run over at a uniform speed, which is hardly probable. It should be noticed moreover, that the lines on the two slopes are in conditions differing notably as regards the adhesion.

Gradient of one in 11. — The temporary piece of line 275 miles long, laid down between *Raincy* and *Montfermeil*, for M. *Larmanjat's* trial (220), had inclines increasing up to one in 11, and curves of 5,5 yards. Thefollowing according to M. *J. Morandière* (*) gives the work done on this bit of line, by two engines, weighing, the one 5 tons, and the other 7 tons :

SECTIONS.	ENGINES OF 5 TONS.		ENGINES OF 7 TONS.	
	Speed.	Load drawn.	Speed.	Load drawn.
	Miles an hour.	tons.	Miles an hour.	tons.
Horizontal :	9	50	5 to 6	90
One in 100 to one in 33	6	22	4 to 5	30
» 33 » 20	5	15	4 to 5	20
» 20 » 14	5	8	4 to 5	10
» 14 » 11	5	5	4 to 5	8

Let us take the last figure, 8 tons drawn up one in 12,5 on the mean, by the engine of 7 tons, and let us assume 8 lbs,8 (or 4 kil.) for the resistance on a level, a resistance but little affected by the curves, on account of the flexibility of the system. The effort of traction measured on the driving-wheels is $(0,080 + 0,004) \times 15$ tons is 1,26 tons, that is to say $\frac{1}{3,7}$ of the adherent weight of 4,666 tons, $\frac{2}{3}$ of the weight of the engine. No doubt that the coefficient of adherence may attain accidentally that value on a metalled road as on rails; but what there is no doubt in, is, that the 7 ton engines only draw with a retarded movement, the load of 8 tons, on the gradients from one in 14,3 to one in 11.

The experiment was removed to *Paris* in 1872, on one of the avenues of the *Trocadero*, with a flat incline in order to try among other things, a rail not projecting. The rail was made, like those of level crossings, of two *Vignolles* rails, allowing the necessary channel for the passage of the flange of the wheel. The tyres being of the ordinary form, with the flange at one side, each of the rails only bore the load in one direction run on, and served simply as a guide, in the other.

The *Trocadero* trial in no way besides modified the negative conclusions which resulted from the *Raincy* trial, and more still from the simple examination of the principles of this pretended system.

Temporary gradient of one in 10, *on the line from Baltimore to Ohio.* It

(*) Memoirs of the *Société des Ingénieurs civils.*

is on this line, the oldest in the United States, that Mr. *Latrobe* established, as far back as 1852, during the execution of the *Kingwood* tunnel, a provisional crossing, under conditions still more difficult than those of the *Board Tree*. This surface line was first made use of for the distribution of materials along the line, then for regular traffic.

The traction was effected by locomotives with eight wheels coupled 4 ft,5 in diameter, cylinders 17 inches × 20 inches stroke, weighing 24 tons, and having a tender of 12 tons. They drew one waggon of 13 tons at a speed of from 9 to 10 miles an hour; the amount of adhesion utilised was thus:

Gravity : $(24 + 12 + 13) \times 100$	4,900 tons
Resistance, approximately 13 lbs, 23 in mean (on account of the curves).	0,294 »
	5,194 tons

or $\frac{1}{4,6}$ of the adherent weight.

The length is unfortunately not given; it was doubtless very short.

This crossing was only in operation for a short time; but it had to be re-established some years later, during the reparatory works of the tunnel. The line was modified, and the incline reduced to one in 14,3.

Only once a train ran down backwards, but without any accident, with all its wheels skidded by the brakes. On such a gradient however, and *a fortiori* on a one in 10, brakes acting only on the wheels are evidently insufficient.

422. *Conclusions.* — And now, what are we to conclude from these examples? In the first place, we must put aside these extreme gradients, such as those of the temporary crossings of the American lines, the short length of which takes off much of their significance, and which were besides favoured with an unexceptionally high amount of adhesion. The best proof, moreover, that they are, even with this shortness, inadmissible in normal working and for serious traffic, is that after having carried out these crossings with a temporary view, it was never dreamed of to make them permanent, and that they gave place, as soon as possible, to less excessive traces.

They are besides curious and interesting as means of hastening a line into work, which presents only a few gaps.

The principal consequence which comes out from the mass of the facts is this: after having for long shirked moderate rates of inclination too much, people afterwards became familiarised themselves with gradients much too steep, and that especially because they had given but little consideration to

one item : the very reduced useful effect of the locomotive, and they resigned themselves thereto. This is a serious consideration, we have dwelt enough upon it; but it is not the only one, far from it. It is only by a regular and continued observation of the working of railways with very steep gradients, that can be judged of to its full extent, the seriousness, rapidly increasing with the rate of inclination, of the drawbacks, the difficulties, the inflictions which they involve. Atmospheric influences affect the regularity of the service thereon quite otherwise than on lines of ordinary section, either on account of the almost constant working of the engines close to the limit of adhesion, or because that limit is, in general, in mountainous regions, lower, and especially more frequently attained than on flatter lines.

The requirements in making up the trains, with regard to the number of brakes are very awkward : they often lead, on lines of variable section, to leaving on certain portions an excess of brake waggons, useless thereon, so as to save changes in the composition of the trains. The use of an engine behind, and the application of brakes, often simple lever-brakes, in a considerable proportion to the rolling-stock, diminish these drawbacks more or less.

Very steep gradients have for consequence, requiring stations provided with very complete arrangements, so as to meet any unforeseen want in remaking and standing the trains; bringing the reserve engines closer together; multiplying the water columns, etc., etc.

If on lines of small traffic, the rate of inclination may, strictly speaking, be carried to one in 33,3, and even to one in 28,6, one in 40 ought to be looked on as a limit which it is very desirable should not be exceeded on important lines. The technical commission of the Union of German Railways adopts this limit for secondary lines as well as for the first class ones. It makes no concession, for local lines, excepting as regards curves, the radius of which can be reduced to 165 yards (insteed of 197), but on the condition of always having a tangent of at least 55 yards between two reverse curves.

It is this gradient which has been decided on for the *St. Gothard*, which is to be passed at the altitude of 3.730 feet by a tunnel of 9,26 miles, up to which will lead gradients of one in 40, and curves of 328 yards at the least. These are very nearly the same as the *Brenner* conditions (412).

For the curves, the extreme limit seems to be 220 yards, and on condition of avoiding the coincidence of these curves with the maximum gradients.

The example of the line from *Alais* to *Brioude* (412, and Pl. CI) proves besides that, as far as that limit, the regular use of ordinary engines, that

is to say with parallel axles, is quite practicable, even for four axles; so that engines with two bogie trucks do not appear, so far, to meet any real want.

Let us not hesitate to repeat once again that in general, the almost impossibility practically, to push the steepness of gradient any farther, results not from the want of adhesion (the examples which precede prove it at any rate) but of the really disheartening smallness of the load then drawn by locomotives; that the insufficiency of the adhesion is little manifest as long as the habitual speed does not go below 7,5 miles an hour; *and that below that limit only, and whatever may be the rate of inclination,* it becomes necessary to seek, beyond the simple adhesion due to the weight, a point of support for the driving wheels. Let us pass on to the examination of the endeavours made with that object.

CHAPTER XIV.

SYSTEM STILL FOUNDED ON THE ADHESION, BUT RENDERED INDEPENDENT OF THE WEIGHT.

423. The sole method applied hitherto, for obtaining adhesion independent of the weight, is founded on a principle long known : a central rail gripped by horizontal wheels, pressed with greater or less force thereagainst. The idea was patented as far back as 1830 by *Vignolles* and *Ericsson;* some engines on their system were constructed for the Panama Railway; later, in 1847, *G. Seller* introduced the principle on a mineral railway in Pennsylvania, where indeed the application seemed little warranted. In France, the central rail was proposed by M. *Séguier*, who at the time was less taken by increasing the adhesion, than by preventing trains running off the line, an occurrence which frequently took place at the outset of railways. His aim was thus solely to connect the head of the train with the permanent way, a connection rendered indispensable according to him, through the insufficiency of the flanges. It was thus a question of a general application of the central rail without distinction of speed, or more correctly speaking, of an application judged to be the more necessary the greater the speed. M. *Séguier* accepted in that case the necessity of horizontal wheels of large diameter, projecting greatly beyond the rails, and evidently very dangerous by that very fact.

Long given up, in France, the idea was resumed towards 1865 by M. *Séguier*, aided by M. *Duméry*, a civil engineer, and always with the same absolute program, the same pretentions to a practical value independent of the conditions of section and of speed; and this time too, it was the adhesion which was put on its trial. It was its pretended insufficiency, not accidental but constant, even at high speeds, that was to be guarded against; and to make sure of being in the right, a value was attributed to it, absolutety imaginary. In a note inserted in the *Comptes rendus de l'Académie des Sciences* (*), M. *Séguier* estimates it at $\frac{1}{20}$; and he does not give this figure as an extreme lower limit, reached at one time or another, nor even as the mean value. It is, according to him, the value which corresponds to " dry weather when

(*) Compte rendu of 1864. 1st half. Page 396.

no humidity lubricates the rails", and as if that does not seem clear enough to him, he adds :

"A train only advances because the driving wheels of the locomotive undergo on the rails, a friction which experiment has demonstrated to be in ordinary weather about one-twentieth of the weight which presses on the driving wheels; thus a locomotive twenty tons in weight, *in dry weather*, *when no moisture lubricates the rails*, finds in the coefficient of friction of its driving wheels, a tractive power horizontally, of *one ton* (!)."

"A locomotive of 60 tons and more to ascend mountains!" cries M. *Séguier* (*), alluding to the twelve-wheeled engine of the Northern of France (262), without considering that if this engine weighs 60 tons, it is not, at all because the adhesion is $\frac{1}{20}$, but because that engine is of most unusual power, of very large and very efficient heating surface; without considering that it is in reality, that is to say per square foot of heating surface, one of the lightest that has ever been made; without perceiving that the working of railways, at every moment and on all sides, gives the most crushing contradiction to this fantastical figure of adhesion $\frac{1}{20}$!

In 1865, MM. *Séguier* and *Duméry* succeeded, in spite of every thing, in interesting the Chief of the State in the success of the system. It is unnecessary to say that a commission appointed to examine their project, formally pronounced against any financial cooperation on the part of the State. As to the system in itself, while giving a most complete criticism thereof, which would have been perfectly useless without the influences which it was necessary, if not to convince, at least to cause to hesitate, the commission concluded that there would be no grounds to oppose an application of the system, in case any company should take a fancy thereto; a conclusion in accordance with the principle of the freedom of industry and which the commission had arrived at, without dwelling on the well founded objections to which the system gave rise, even on the score of safety. But it was quite evident that no proper company would be induced to profit by the permission under the condition admitted by MM. *Séguier* and *Duméry*, that is to say for lines with flat gradients, and high or mean speeds.

Persisting in his ideas, M. *Duméry* read later, before the Academy of Sciences (**) a note in which he returns to the charge, upholding his statements purely and simply:

"If", said he, "the engine can, by reason of the *new* mode of adhesion, only weigh

(*) Compte rendu de 1864. 1st half. Page 392.

(**) Meeting of the 15th Jan. 1870.

30 tons instead of 60, and produce the same work, it is evident that the following advantages are realised, etc., etc."

No one most certainly will contest the advantages to be gathered from such progress; they would be greater still, if instead of 30 tons, the engine only weighed 15! But where is it then, this marvellous engine, which, with equal power, only weighs the one half of ordinary engines? How could it be the engine of MM. *Séguier* and *Duméry*, which is only an ordinary engine, hampered with additional organs which greatly augment both its weight an dits resistance?

It would not seem that errors similar to those we have already brought up, should require refutation. But when they are found to be thus deeply rooted, even in persons occupied in industrial pursuits, the ordinary run of whose ideas, the world in which they live, should put them on their guard against such errors, we must not treat them too trivially, and so allow them to gain more and more credit.

424. *Fell's system.* — The useful, applicable property of the central rail and of the engine appropriate to its use, is (need it be said?) to permit to be pushed to a greater extent than with engines with the simple adhesion due to their weight, the conversion of the speed into tractive effort, to utilise the power of the engine at a lower speed. It is under these special conditions, the only logical ones, that the system was taken up by Mr. *Fell.* In 1863, he tried at *High Peak* near *Manchester*, on a gradient of one in 12, his first engine constructed at the *Millwall* workshops, and which served for the preliminary trials at Mount Cenis. To Mr. *Fell*, the merit was due of making an intelligent application of the central rail, on a large scale, and of organising regular working under very difficult conditions; and the Mount Cenis Company who succeeded him, resolutely followed in the way he had traced out, and that in the middle of obstacles of every nature, the least serious of which was not its financial position. To make the locomotive cross the great chain of the Alps at the altitude of 6.972 feet, to make it run along the edge of bottomless abysses, through curves of 44 yards radius, on gradients of one in 12,5; to succeed during several years in avoiding any serious accident, to insure safety under conditions so extreme, so new, is assuredly a remarkable work, which does honour to the intelligence and devotion of those who accomplished it, and which will worthily take its place in the history of railways. But it does not appear to us to have advanced one step the great problem of the crossing of chains of mountains by railways; and if the admirable although costly experiment of Mount

Cenis proves anything, it is, — and precisely because the experiment was so well made that it is only the more conclusive, — that something else must be found!

In spite of relatively favourable economical elements, seeing that the roadway was gratuitously handed over by the two States, subject to a little work in reducing the far too sharp curves, the Mount Cenis line could not be seriously made use of for goods. If it took away from the road the passenger-traffic, and that incompletely, it was unable to contest therewith for the goods-traffic. It took not a single ton into Italy of coal, of which that country was then so much in want. Very far from that; it had even to carry by the road, the coals for it's own consumption. It will be urged, no doubt, that such arose from the temporary and precarious position of the company, which was only making an experiment for a short time and not carrying on normal working; to the insufficiency of its rolling-stock, which that very position did not allow to be seriously constituted; but, if this material impossibility hindered the company not only from developing the goods traffic, but even from taking simply a humble part therein, there was another impossibility, altogether absolute: that which resulted from the raising of the tariffs, inherent to the very conditions of the trace, and which would have been but slightly reduced, even had it been a question of a regular permanent working.

That settled, let us examine the system, well worthy of interest in itself, and for which some applications are no doubt reserved in the future, under conditions less extreme as regards trace, less exhanced by the climate, and of a more restricted, more exclusively industrial character, than that tried at Mount Cenis.

425. *Permanent way.* — The gauge was reduced to 3 ft, 6, on account of the narrowness of the strip of the road conceded, and by the extreme sharpness of the curves, 45 yards.

The smallness of the distance often between reverse curves, did not allow the external rail to be raised in proportion to the radius and the speed. The central rail, is fortunately, an absolute guarantee against completely getting off the line. Even if it could be done without as regards the adhesion, it would be perfectly indispensable, even on a less extreme trace than that of Mount Cenis.

The central rail perfectly allows the immediate application of very energetic brakes, without interfering with the ordinary brakes acting on all the wheels.

is the true, the best guarantee, not only against getting off the line, and

in this case a train off the line might simply be a train swallowed, but also against the breakage of a coupling, which might be not less disastrous on such gradients as one in 12

It was formed (Pl. LXXXI, *figs.* 4 to 6) of an ordinary rail r, bolted flatwise on to iron supports s, s, themselves bolted on to a line of longitudinals fixed to the cross sleepers, and held by fish-pieces t; the horizontal axis of the rail was 10 ins, 5 above the carrying rails.

Subject on each side to pressures nearly equal, and directly opposite, the central rail has no tendency to bend, but this equality is only, and then only approximately, on straight lines. On curves, it is the central rail which neutralises the centrifugal force and the stiffness of the vehicles. It has thus a marked tendency to turn over towards the outside.

It has been objected that the central rail destroys the effect of the conicity and the play in the road, which are then without utility, as it renders the position of the vehicles across the line invariable. Nothing however, prevents on curves, the central rail being brought nearer the outside rail, by half the amount of the play. But what is correct, is, that with the limits which these two elements : conicity and play, cannot exceed, they only reduce in the very slightest degree the relative slipping of the conjugate wheels, on curves as stiff as these in question.

One difficulty which presents itself at first sight, is that of the level-crossings. These were numerous on the Mount Cenis line, the rails, restricted o the condition of keeping always on the side of the drain, having often to pass across the road from one side to the other. The central rail could evidently not be dealt with, in the same way as the carrying rails. The gap which for these latter corresponds only to the passage of the flanges of the wheels, ought for the former to leave on each side the passage free to the wheels of the road vehicles. Level crossings must thus be as much as possible avoided whereever the central rail is necessary, either by the gradients or the sharpness of the curves. It might be broken off for a yard or two; an intelligent driver would be able to do without this little piece of central adhesion, on the ascent; and on the descent, he ought always to be in a position to pull up before getting to the level crossing, in the case (which would besides be signalled to him) of the crossing not being free. If it so happened that a train stopped, on the ascent, just on the crossing, which would render it impossible to start at that spot, the driver could get out of the fix by going back a little, so as to start on the central rail, and thus get up enough speed to run over the gap, a slightly slackening.

The suppression of the central rail at the level crossings, was not able however be laid down in principle. It was necessary at the same time that the rail should be completely removed, to leave the passage for the cross free. It was with this object set up on jointed supports, which allowed it to be lowered to the line. On a curve it was made in two parts which were removed in contrary directions. This does not seem to be a very satisfactory arrangement; but it caused no accident.

As the central rail disappears on every point where the trace of the line allows, the result is that the train takes on to it and quits it very frequently.

The portions are tapered off at their extremities, so that the horizontal wheels may not strike against them every time, but enter gradually into pressure; but this discontinuity requires, on the descent, the most constant attention on the part of both, drivers and brakesmen. Besides the ordinary brakes, acting on the wheels, each vehicle is, like the engine, provided with a central brake formed of an articulated parallelogram, the long sides of which are strongly pressed against the rail. In this state, the parallelogram would not fail to strike against the central rail, even tapered off. Care must thus be taken, immediately on leaving one portion of rail, to unscrew the brakes before getting to the next one.

The solidarity of the two wheels of the same axle, which, as we saw (186), had disappeared in the carriages, still existed in the engines, where it would have been difficult to suppress it without further increasing their already great complication.

426. *Locomotives.* — The *Fell's* engine is in principle, an engine with eight wheels coupled: four vertical and carrying, giving the adhesion due to the total weight, and four horizontal ones giving the adhesion due to the pressure, variable at will, which they exert on the central rail. It is a difficult problem of practical mechanics, the application of this double motive apparatus, above all to an engine of a considerable power, the wheel base of which is very narrow on account of the narrow gauge, and very short on account of the extreme sharpness of the curves. Thus it is impossible to avoid, both longways and crossways, a considerable amount of overhanging, very detrimental to the stability of the engine. The low speed, which is the sole ground for the existence of a locomotive towing itself along a central rail, reduces however this drawback, and the connection of the engine with the central rail avoids the dangers from its want of stability.

At the very time when the working of the temporary line stopped, Mr. *Fell* was occupied with his third type. In the oldest and in the most

recent, each of the two systems of wheels has its special motor, that is to say, its pair of independent cylinders. In the second, the two systems are driven by the same pair of cylinders.

First type. In the first type, that which served for the preliminary experiments at *High-Peak* near *Manchester*, the bearing wheels 26 ins,5 in diameter, received motion from two exterior horizontal pistons 11 ins,75 in diameter, with a stroke of 18 inches; the horizontal wheels, 16 inches in diameter, were driven by two pistons 11 inches in diameter, with 12 inches stroke, having their rods placed horizontal in a line with each other, in the vertical plane of the engine.

The driver presses the wheels on to the central rail by means of a combination of levers and bevel-wheels, which imparts a rotatory movement to a cross shaft, bearing a right and left hand screw, and thus separating or bringing together two frames, attached to the lower brackets of the vertical wheels. It is evident that this transmission cannot be entirely rigid : *Baillie* springs, placed between the frames and the brackets, give the system the necessary elasticity to allow the driver to graduate the pressure, so as to compensate for the little irregularities of the central rail. A stop limits the pressure which can be put by the driver on the wheels.

The slight mobility of the lower brackets alters the verticalness of the shafts; but within the limits where it is necessary, this mobility does not sensibly affect the driving crank, placed immediately above the upper bracket, which is fixed.

The pressure applied by the springs is divided between this upper bracket and the wheel, and the latter only receives three quarters of it. This is one of the drawbacks, quite secondary however, of this type of engine.

The mechanism of the horizontal wheels presents a special difficulty, that of the passage of the dead points. For the vertical wheels, these points are passed, as in all locomotives, by the cranks being at right angle to each other.

It is not the same with the horizontal wheels; these are not like the others coupled together two and two, from one side to the other of the engine, by a common axle. Nor can they be so by a simple connecting rod, as their rotations are in inverse directions. However, each of the two lateral systems of vertical shafts, if it were independent of the other and driven by a single crank, would be in the same position as the axles driven by the middle in M. *Roy's* engine (359). Either then, two cranks at right angles must be applied to each shaft, or between the wheels of the two sides, a connection which takes the place of that which is established for the vertical, by the

common shaft, or to do both one and the other, as in the new engines constructed for the *Cantagallo* (Brazil) line (431).

We shall not dwell either on the solution applied to the type in question, nor on its other details of construction. Preferable, in principle, to the following type, the latter presented numerous imperfections of detail, inseparable from a first trial.

The heating surface (420 square feet) was insufficient; the mechanism of the horizontal wheels, too cramped, involved very considerable passive resistances, as was proved by the relatively very small power of this partial motor, although according to the dimensions, the total power of the boiler ought to have been equally divided between the two groups of cylinders. One of the serious drawbacks of the central position of one of these groups, was also the difficulty of withdrawing the horizontal wheels from the oil which escaped from the machinery.

It might be thought, that, thanks to the horizontal wheels, to the pressure almost unlimited in appearance, which can be exerted between them, an amount of adhesion, so to say indefinite, is available, and that it is unnecessary to have recourse to sand. It is however nothing of the sort, as will be shortly seen. Thus, from the very outset the necessity has been admitted of employing sand (216) not only for the vertical wheels, but also for the horizontal ones; for the latter however, the thing is less simple; the sand must be got to stick to the vertical surfaces. In the primitive engine, the tube curved back horizontally received a little jet of steam which threw the sand on to the wheels, where it was held by the moisture arising from the condensation.

Second type. More impressed with the complication involved by the double motive mechanism than by its incontestable advantages, the engineers of the Mount Cenis line modified the program, and adopted one single pair of pistons, driving both the groups of wheels. This was a great simplification in appearance, but experience soon condemned it; the least of the drawbacks was that which the solidarity of the eight wheels involved, that is to say the slipping which intervenes, and becomes aggravated as soon as the least change occurs in the equality of the diameters The running *blank*, of the horizontal wheels, wherever there is no central rail, is also a grave objection to the one single motor.

In this second type, executed at first by *Cross* of *St. Helens* (table in No 430) two interior horizontal cylinders, each having its axis in the vertical plane of the shafts of the two horizontal wheels of the same side, drive these wheels directly. The pistons-rods elongated in front, impart an oscillatory movement to a horizontal auxiliary shaft which itself drives the hind ver-

tical wheels by means of cranks, connecting rods, and a guided rod, the oscillatory movement being transformed into a movement of rotation, by a suitable ratio between the lengths of the cranks of the shaft, and of the wheels.

One of the weak points of this engine being the mode of connection between the mechanism of the horizontal movement of the two sides so as to determine the direction of rotation at the dead points. This office was filled by oscillating beams, which underwent frequent breakages.

The number of *Baillie* springs has been brought, for each horizontal wheel, from two to three. The total pressure on the central rail can be carried to 20 tons. In the position corresponding to that limit, the distance between the opposite edges of the wheels, free, is 4 ins, 13. The width of the rail being 5 ins, 27, the sum of the compressions of the opposite springs, when the wheels have run on to the rail, is 5,27 — 4,13 = 1,14 inches, which gives for each of the three springs a compressibility of 0,019 of an inch per ton, only. But this great amount of stiffness in the springs is necessary. If they were more flexible, the shafts of the horizontal wheels would made angles too large with the vertical, and the fixity of their cranks would be too much interfered with.

This engine has an advantage over the preceding, but it is about the only one, of not exposing the horizontal wheels to the oil dropping from the central mechanism. But the position of the cylinders along the axis is in no way a consequence of the independence of the two groups of wheels; and if with two cylinders, the mechanism of the horizontal wheels is simplified, it is at the expense of the vertical wheels, the driving of which becomes on the contrary very complicated.

Cross's engine failed besides in the want of resistance of several parts. The efforts coming into play had not been properly taken into consideration, and too much attention was given to lightness. Thence breakages, pieces distorted, etc. This engine weighed : empty 13 tons; full 16,5 tons; after the weak parts were strengthened, 17 tns, 1 at the most, 16 tns, 2 on the average. The special mechanism of the horizontal wheels weighed 2 tns, 6, or 16 per cent. of the mean weight.

Twelve engines of the same type, save some improvements of detail and a certain increase of power (430) were delivered in 1868 to the Mount Cenis company by the firm of *Gonin*.

Third type. But the frequent breaks-down soon led the engineers to return to the principle of the primitive plan, that is to say to the application of a special motor to each of the groups of wheels. The execution of this program was confided to MM. *Cail and Co.* (Pl. LXXXI, *figs.* 1 and 2).

The four cylinders are horizontal, and placed laterally: those which drive the carrying wheels (c, c, *fig.* 2), outside the wheels; those (c', c'), for the horizontal movement, inside, and higher than the first. Each of the connecting rods b, b, of these, drive the crank m of a vertical shaft A, A, on which is keyed a toothed wheel in cast steel S which transmits the rotation to pinions themselves keyed on the shafts ω, ω', carrying at their lower portions, the pressure wheels $\rho\,\rho$, $\rho'\,\rho'$. The junction of the apparatuses of the two sides is established by the transmitting wheels S, S. Their primitive circumferences have for radius the distance of the shaft A, to the plan of symmetry of the engine and of the central rail, so that they gear also into one another, and as these two mechanisms once regulated, that is to say with the two cranks m, m', at right angle, the connection established by the intermedium of the wheels S, S', renders this position invariable: excepting the very slight deviations arising from the wear of the cast steel teeth.

Here again reappears gearing, under a form and conditions very analogous to those which had been thought of in the infancy of railways. As far back as 1814, *George Stephenson* applied an identical contrivance for passing the dead points in an engine with two vertical cylinders, placed in the mean plane (*fig.* 7). Each of the connecting rods B, B' transmitted the rotation to one of the axles by gearing; and the rectangular position of the two cranks m, m', was assured by the intermediate pinion π, of the same diameter as the pinions p and p', bound by this connection to have constantly the same angular velocity. The pinion π had no other function.

The two toothed wheels were 2 feet, and the three pinions 1 foot in diameter.

The arrangement in question avoids also the radical objections which the endeavours mentioned above give rise to, and the failure of *Norris's* and *Engerth's* gearing (350) cannot be opposed thereto, a failure due above all, to the variation of the angles which the planes of the toothed wheels form between them.

The slight mobility of the axles ω, ω', which come up to or go from the mean plane, according as the wheels ρ, ρ', are free or pressed against the central rail, has no drawback, these axles keeping always their direction parallel to the fixed axles A, A'; and the taking on of the teeth of the wheels S, S', and of the pinions p, p (*figs.* 1 and 2), offers no obstacle to the displacement of the latter, within the limits necessary for the action of the horizontal wheels. They receive the pressure of the stepped springs r, r

(*fig.* 2), tended by means of screwed rods t, t, carrying pinions s, s (*fig.* 1) driven by endless screws v, v, round the shaft θ.

The cylinders of both pairs are 13 inches in diameter, and have 18 inches stroke, a much more favourable proportion than in the preceding engines with two cylinders, in which the diameter and stroke were the same: 16 inches.

Diameter of the wheels..	carrying................................	2,79 feet
	horizontal................................	1,64 »

The wheel base is only 7 feet long, for a length of frame of 21 ft, 16; the centre of gravity is, moreover, relatively high, which explains the mediocre stability and very jerky running of these engines; but these faults are much reduced by the connection with the central rail.

The driving wheels are naturally behind, and are driven by connecting rods k, h (*fig.* 2), 6 ft, 84 long.

The two admissions are, at will, independent, or coupled together by locking the levers; in this case they can be worked by one screw.

The wheels are keyed on their axles at 3 ft, 37 between; but fortunately (235) they do not limit the diameter of the boiler, which is 3 ft, 67.

The bearing springs in front R, R, placed within the inside longitudinals, are directly on the axle-boxes; the hind ones R', R', are outside, raised up, and placed immediately above the wheels. Their projection outside of the axle-boxes is made up by a bracket O H, an arrangement already applied, as we have seen, to other engines (290).

Like the simple vehicles, the engine is provided with four horizontal rollers g, g, 0 ft, 82 in diameter which on account of the great interval between them, 8 ft, 07 guide it effectually.

The brake, which is very powerful, is formed of two jaws M, M, griping the central rail and worked by means of the screw-shaft with right and left hand threads τ, τ, of the conical gearing ω, and of the crank μ.

This engine is remarkable as a study of new mechanical arrangements, and for relative lightness. With a heating surface of 872 square feet, very effective on account of the considerable diameter and the short length of the tubes, it weighs empty 21 tons, or 55 lbs per square foot of heating surface, and that in spite of the numerous special organs which form at least the $\frac{1}{6}$ th. of that weight; in no part however has strength been sacrificed to lightness.

The Northern of France engine with twelve wheels and four cylinders only weighs 42 lbs, 77 per square foot of heating surface. This is very nearly the

same as the relative weight of the Mount Cenis engine, if from the 55 lbs, $\frac{1}{6}$th thereof be deducted for the weight of the special apparatus for the central rail.

There is at the same time no other circumstance in the Mount Cenis engine favourable to lightness but the narrownes sof the gauge, which reduces the length of the axles, and of some other parts, and the small diameter of the wheels.

Effort of traction referred to the pistons.

1. Vertical action: $d = 13$ ins. | $l = 18$ inches | D = 2 ft, 62. take $p =$ (6 atm) 88 lbs, 12 on the inch, we have $\frac{p d^2 l}{D} = 3$ tns, 51.

2. Horizontal action: the effort of traction is $\frac{p d^2 l}{D'}$ multiplied by the ratio 0,65 of the gearing; p, d, l have the same values, and $D' = 1$ ft, 64; we have thus 3 tns, 8.

In reality, the total effort of traction is divided almost equally between the two groups of wheels, the excess of the figure for the horizontal action compensating for the excess of the passive resistances, involved by the gearing.

A higher pressure in the boiler would allow a mean effective pressure to be attained, of more than 6 atm. on the pistons, and, consequently, a greater effort of traction. But the corresponding boiler pressure, 10 atm. should not be much exceeded. In some cases however, now-a-days they go as far as 170 lbs on the inch. (11 atm. 6) (434).

According to Mr. *Ed. Barnes*, the engineer of the Mount Cenis railway, the two cylinders engines are preferable to the others. He remarks that if the latter have done good enough work between *St. Michel* and *Lans-le-Bourg*, it is because the stiff gradients are relatively short thereon, and that on the long gradients between *Lans-le-Bourg* and *Susa*, there would not have been enough steam for the four cylinders. The *Gouin* engines, with four cylinders were, in effect, devoted to working the first section, and excluded from the second; but nothing proves that they were so excluded on the grounds stated by Mr. *Barnes;* the principal ground seems to be that the *Gouin* engines pass more easily through the curves of 45 yards, than those of *Cail*. The objection would besides be, to the execution, to faulty proportions, and not to the principle.

427. In any case Mr. *Barnes* tried to simplify, in the case of the two cylinders engine, the connection between the two horizontal mechanisms, for passing the dead points. He thus, and before knowing of the *Cail* engine, had recourse to gearing. An auxiliary shaft m (Pl. XCI. *figs.* 1 and 2), the bearings of which are hung from the longitudinals, carries two pinions p, p, gearing with two wheels s, s, keyed on at the level of the shaft m, on the vertical moving shafts of the horizontal action. The shaft m insures thus

the equality of the velocity of rotation of the two motive shafts, and, consequently, the relative invariability of position of the cranks M, M′, which drive them. The gearing employed is derived from the endless screw. It is the particular case of the *tangent screw*, in which the wheel hollows to a throat round the screw with helicoidal teeth : this screw is the pinion p.

A trial of this method of connection was made on the engine No 9, but without success. The bronze endless screws broke; they were replaced byothers, in cast steel, but then occurred other damages : broken piston-rods, bent connecting rods, etc. The author attributes this failure to the defective state of the engine to which the system was applied : crooked crank pins, unequal diameters of the horizontal wheels, persistant bending of the connecting rods, etc.

We are not in a position to discuss these allegations, or to judge of their value.

428. *Example of the work of engine No* 2. — We shall quote the results of an observation made on engine No 2, of English make (430).

Engine full : 17 tons.
Train hauled : 24 tons at 7,71 miles (9,8 feet a second).
Mean rate of inclination : one in 13 (= 0,077).
Gravity : 77 (17 + 24).. 3,15 tons
Resistance : 11 lbs (0,005) for the waggons and 22 lbs (0,010) for the engines per ton of weight and of pressure on the central rail : this pressure being 12 tons.
$5 \times 24 + 10(17 + 12) =$ .... 0,41 tons

Or.. 3,56 tons

The increase of resistance on the curves of 44 yards has not been reckoned, because the inclination is reduced thereon by 3 per cent. The figure adopted for the resistance is besides considerable on a straight line, at so low a speed.

No slipping taking place, the adhesion was at least, although the rails were wet, $\frac{3,56}{29,00} = \frac{1}{8}$. Without the action of the pressure wheels, which, according to the bases admitted, would have reduced the resistance by $22 \times 12 = 264$ lbs, the engine could not have done the same work unless the coefficient had exceeded $\frac{3,56 - 0,120}{17,00} =$ over $\frac{1}{5}$.

Thus at about 7 miles an hour, the adhesion due to the weight would be very generally insufficient on account of the state of the rails, and the lightness of the engine. The coefficient must be taken as low as $\frac{1}{12}$ when there is hoar frost; and if with this there should happen to be any derangement of the sand-boxes, the total adhesion with 12 tons on the central rail falls to $\frac{17,00 + 12,00}{12} = 2,40$ tns, which is insufficient even for a train

of only 16 tons, which requires an effort of 2 tns, 91. They would have, with a pressure of 18 tons on the central rail: $\frac{17+18}{12} = 2$ tns,75; and carrying that pressure to 24 tons, $\frac{17+24}{12} = 3$,tns 4, a still insufficient amount for a train of 24 tons.

429. *Causes which limit the pressure on the central rail.* — Many engineers think that there is no drawback to making use of a pressure of 20 tons on the central rail, and that it can even be carried to 24 tons. In fact, this pressure is more limited, and ought to be so.

The nominal limit was 24 tons; but the drivers had a great aversion to go so far; generally indeed they remained far within that. Too great a pressure determined in the parts of the horizontal action, strains which often made themselves manifest by breakages, requiring long and costly repair; it enhances very remarkably the resistance, particurlarly on curves; it involves shocks on taking on to, or quitting the central rail, which the drivers always did without previously taking off the pressure. The last engines (*Cail*) of 26 tons full, and 25 tons on the average, drew 25 tons (4 carriages) up the one in 12,5 gradients, like that of *Termignon;* it is only on these inclines that the horizontal action was made use of; it was sufficient under these conditions for the adhesion to go down to $\frac{1}{12}$ for it to become insufficient on one in 12,5, even with the pressure of 24 tons:

Gravity : $0{,}08\ (25 + 25) =$	4,00 tons
Resistance : $5 \times 25 + 10(25 + 24) =$	0,61 »
Effort of traction : (without reckoning increase on curves)............	4,61 »
Adhesion : $\frac{25{,}00 + 24{,}00}{12} =$	4,08 tons

As it was preferred to remain much below 24 tons pressure, because breakages of the machinery were particularly dreaded; as besides the adhesion at about $\frac{1}{12}$ and even less often occurred, the result was that slipping, instead of being completely done away, as might have been thought, was on the contrary very frequent.

The *Gouin's* engines, weighing full, 22 to 23 tons, draw three carriages (19 tons) through the numerous curves and return curves of the mountain, that is to say between *Lans-le-Bourg* and *Susa.* I made several journeys on these engines in bad weather, the rails being very slippery. I never saw the driver go beyond a score of tons on the central rail, in spite of frequent slipping.

Instead of having recourse, as in the first engines, to a jet of steam to throw the sand down on the wheels, and make it adhere thereto, it was in the *Cail* engines, the wheel itself which took up the sand; the box containing it, being pierced with an opening into which penetrated a segment of the wheel, pressed by a sort of block or piston acted on by a spring, and which thus took up sand mixed with a little resin; but too much use must not be made of sticky matters, which if they make the sand hold, are on the other hand very detrimental to the adhesion of the wheels.

If, on the Mount Cenis line, slipping was not otherwise feared, that means only that it was less dreaded than breakages, the consequences of the exaggeration of the pressure on the central rail; for there as everywhere else, and still more on account of the special conditions of the case, slipping was attended with serious drawbacks, among which must be reckoned the breakages themselves, which it often enough causes, through the excessive speeds at which the parts of the machinery then run.

If the two groups of wheels were not to commence slipping exactly at the same moment, the slipping of the one would involve almost immediately that of the other, on which the whole effort of traction would tend to be brought. The complication of the mechanism would enhance this drawback. There was another too, a serious one, especially for engines which like those of the Mount Cenis had to work on the ascent, close to the limit of their power. Slipping, if it cannot be immediately stopped, or if it be repeated several times in a very short space of time, expends such a quantity of steam, as to lower the pressure rapidly. Hence an inevitable stoppage until the pressure gets up again, which it does very slowly, the fire being only drawn up by the blower; and it is often much better to uncouple the engine and run it alone. If, at the same time the slipping has used up all the water, the engine has to go to the nearest water-column.

Instead of being exposed to this alternative : excess of pressure on the central rail, or slipping, it would have been much preferable in general, to reduce the load. But the stations at which the trains were formed, *St. Michel* and *Susa*, were not always informed as they should have been, as to the atmospheric conditions and the value of the adhesion in the upper regions of the mountain; thence frequent slipping, loss of time in trying to start, and sometimes the necessity of prolonged stoppages in order to get up steam again.

430. *Conclusions.*—On the whole, the application of the *Fell's* system to gradients reaching as high as one in 12, and curves as sharp as 45 yards

radius (with a gauge of 3 ft, 6) cannot be considered as a solution applicable to lines of great traffic. To economise on the general cost, so as to burthen special expenditure, is, according to the cases, a good or an objectionable proceeding. If there were thus carried out a crossing, important by its geographical conditions, naturally destined for a great traffic, this traffic would turn a deaf ear to that appeal, because the tariffs would keep it away therefrom; and the restricted traffic which would have accepted that road for want of a better, would leave it the instant an other offered better terms; so that a line placed in the first rank by its position would fall back definitively into the second, or even lower, on account of the errors in carrying it out.

Compared to the great line, open since 1871, the passage in the open air, across the neck of Mount Cenis, had an excess of altitude of 2,625 feet, and an excess of 7,5 miles in length. The amount of capital represented by such an infliction on a considerable traffic can be easily conceived, independently of the difficulties and chances of interruption, inseparable from the higher crossing.

The *Fell* line only established the continuity between the French and Italian lines, under the condition of double transshipment; but it was principally a question of an experiment commenced somewhat too late, and from which the rapid progress of the work of the great tunnel took away all importance from the point of view of immediate remuneration. In any case, the troublesome influence of the transshipment was relatively slight in this case, precisely because it dealt with excessively costly haulage; and this high cost is incidental to the system, that is to say to its principle: the application of the locomotive to gradients so excessive. As to the central rail and the horizontal wheels, they are only the method of carrying out, and at the same time indispensable, in any state of the case, for safety. The reduction of velocity which the adhesion of the central rail allows of, diminishes without doubt the drawback on which we have so often dwelt, that is to say the relative smallness of the load drawn; but all that can be said is that the situation becomes scarcely tolerable, and that the central rail and the pressure wheels are far from freeing the traction, as was believed, from all the difficulties arising from the want of adhesion.

If is often said, that provided the railway crosses the great natural obstacles, the expense is a matter of little consequence. This is true, within certain limits, as regards the cost of construction; but in no way as regards the working expenses. If the traffic is very active, an excess, even considerable, burthens the unit of traffic but slightly. The working ex-

penses, however, tell on every thing; for passengers, speed, comfort, safety may cause high tariffs to be accepted; for goods trains, for many raw materials, especially the low value of which prohibits costly transport, it is another matter. Coal, for example, does not adopt a channel, by which its price would come too high; a reduction of 4 or 5 shillings a ton at the place of consumption will often serve to develop branches of industry, languishing until then, and exercise a profound influence on the railway itself.

It must not then be said that, provided a passage is had, no matter at what cost the object is gained.

The *Gouin* engines consumed on the average:

For passengers..	74,7 lbs per mile.
For goods..	80,4 » »

The consumption on the descent being almost zero, the expenditure on the ascent is about the double of these figures. A speed of 6,25 miles an hour, the consumption of 160 lbs, 8, represents 996 lbs, 5 per hour; and admitting 7 lbs, 5 of water evaporated per lb. of fuel, a gross evaporation of 7473 lbs, 7, or 11 lbs per square foot of heating surface.

From the *Giovi*, the *Semring*, etc., engines, a production of steam is required of from 8,5 to 9 lbs, 6 per square foot per hour; and it is agreed that it is expedient not to exceed this figure. Higher figures must not, however, be absolutely termed excessive; they may moreover be the natural consequence of the different ratio between the direct and indirect heating surfaces.

The experience of the Mount Cenis line seems also to confirm the opinion that a locomotive low speed line, may be laid without hesitation along the side of a road. Horses soon get accustomed to it, especially when it is not endeavoured, as is sometimes wrongly done, to conceal from their view the cause of the noise. It is true that the horses and mules which travel over the Mount Cenis road are in general neither frisky nor shying.

431. *Frozen engines.* — It happened pretty often, on Mount Cenis, that engines caught and enveloped in the snow have had their mechanism covered with a layer of ice. Mr *Barnes* had the idea of adapting an india-rubber tube to the *Giffard's* injector and thus directing the steam on all the frozen parts. In acting in this way on an engine completely frozen, the mechanism was perfectly freed in about an hour. The value of this method which by the way is one occurring naturally, could have been better estimated, if some difficulties arising between the company and Mr *Barnes* had not put a stop to its application.

432 Principal particulars of the engines which ran on the Mount Cenis line.

	2nd TYPE (424).			3rd TYPE (424).
	No 2 (*a*) (1 engine).	SERIES 3-12 (10 engines).	SERIES 13-14 (2 engines).	SERIES 15 TO 18 OR A-D. (4 engines).
Commenced running.........	May 1865.	15 June 1868.	15 June 1868.	9 th. Nov. and 5 th. Dec. 1869. 5th. and 21st. Jan. 1870 (*b*).
Maker's name...............	Cross.	Gouin.	Gouin.	Cail and Co.
Grate surface...............	1001 sq. ft	10.01 sq. ft.	12.20 sq. ft.	12.43 sq. ft.
Heating surface — fire box............	56.51 »	56.51 »	62.86 »	63.18 »
Heating surface — tubes...............	516.67 »	576.88 »	611.40 »	819.92 »
Heating surface — Total...........	573.18 »	633.39 »	647.26 »	883.10 »
Number of cylinders..........	2	2	2	4
Diameter do	15 inches	16 inches	16 inches	13 inches
Stroke......................	16 »	16 »	16 »	16 »
Capacity of the tanks — water.............	2 tons	2.37 tons	2.37 tons	3 tons
Capacity of the tanks — fuel.............	29.73 c. ft.	33.54 c. ft.	38.85 c. ft.	35.32 c. ft.
Weight.... — empty...........	? tons	18,597 tons	18,597 tons	21 00 tons
Weight.... — running..........	17.00 »	22,00 »	23,467 »	26,00 »
Load drawn on a mean gradient of one in 14..........	(*) 24.00 tons	(*) 26.00 »	(*) 30.00 »	(*) 30.00 »
at the mean speed of.........	7 miles.	10 miles	10 miles	11 miles

* Figures supplied by the Company.

OBSERVATIONS.

(*a*) No 1, with four cylinders, had long been taken to pieces.

No 2, served for the experiments of 1865. Not authorised to run on the French portion; it was made use of at *Susa*.

(*b*) Employed by preference on the lower part of the line, from *St.-Michel* to *Lans-le-Bourg*.

433. *New engine on Fell's system.* — The *Fell's* system is on the point of receiving a new application, in Brazil. Like all the lines starting from the sea-shore, that which goes from *Rio de Janeiro* towards the district of *Cantagallo*, the centre of an important coffee production, meets with the mountains of the coast, and for several years has stopped at their foot at *Caxoeira* (*). It is to cross these mountains that the central rail has been adopted. Once the table land reached, the section enters into ordinary conditions, and the central rail disappears. The engine, acting then only by means of the adhesion due to its weight, that is to say with its outside cylinders alone, will run as far as *Nova Friborgo*, a pleasure resort, renowned for its salubrity. The conditions bear a great analogy with those of Mount Cenis. For 10 miles, the gradients vary from one in 20 to one in 12. According to Messrs *Manning and Wardle* of *Leeds*, the constructors of the engines, the height gained on

(*) This town, situated in the province of *Rio de Janeiro*, must not be confounded with *Cachoeira*, which belongs to the province of *Bahia*.

8 miles would be about 3.592 feet; but this figure, which corresponds to a mean inclination of one in 11,5, is somewhat exaggerated. The radii of the curves vary from 110 to 45 yards. The gauge is also 3ft, 6, although the gauge between *Caxoeira* and *Rio* is 5 ft, 25.

As it is a question of a definitive concession in this case, and not of a simple experiment, this line will be established, according to Mr *Fell*, under quite different conditions of solidity that at Mount Cenis; the working will not besides have to contend with the difficulties of the Alpine climate.

Although the cost of haulage per train mile, which at first went up to 4 shillings at Mount Cenis, was notably reduced afterwards, a still further considerable reduction is hoped for, from the *Cantagallo* engines, in which the gearing has been done away with. The very ingenious artifice by which this is effected, consists in treating the two vertical shafts on each side of the engine, the one as a moving axle driven by two cylinders, and the other as an axle coupled with the first. Let us suppose at first the assimilation complete. The first consequence will be the inversion of the two cylinders, placed the one above the other in the plan of the two vertical shafts, driving the moving shaft by two cranks at right angles, the other by an ordinary coupling.

Applied thus, the principle would require, for the horizontal wheels, four cylinders, two on each side (Pl. LXXXVI, *figs*. 18 and 19). But this complication is avoided by employing only two cylinders, superposed in the plane of symmetry of the engine, and causing each of the pistons to act at the same time on the right hand driving-shaft D, and on the left hand one G (*fig*. 2). For this it is sufficient to apply to each of the rods a cross-head T, the length of which is the distance between the centres of the wheels in contact with the rails. The upper cross-head drives by two rods *b*, *b'*, the system of upper cranks. The lower cross-head drives in the same way by two equal rods the second system of cranks at right angles to the first (*).

Heating surface..................................	773 square feet
Diameter of the carrying wheels.....................	2,33 feet

(*) We read in a note inserted in the proceedings of the *Société des Ingénieurs civils*, meeting of the 6th Septr. 1872 : « This settled, if by means of suitable cross heads and driving rods, it is so arranged that the upper cylinder works the upper cranks, *respectively al right angles, of the two shafts*, and that the lower cylinder works in the same way, the lower cranks, we see that, at each quarter revolution, each cylinder will cause the dead points of the four cranks to be passed successively, and there will thus result, without any need of recourse to any auxiliary piece, the coupling of the two groups of horizontal wheels.» It is evident that the statement in italics is erroneous, and that each piston can only drive two parallel cranks.

Outside cylinders, diameter........................	13 inches, stroke 14 inches
Diameter of the horizontal wheels..................	1,84 feet
Inside cylinders, diameter.........................	13,58 ins. stroke 12 inches
Weight of the engine empty.........................	25 tons
Do do full	30 to 31 tons

The pressure of the horizontal wheels on the central rail, can be pushed up to 40 tons. But the drivers would no doubt take great care not to work up to that by a long way (427).

The wheels, the tyres and all the parts of the mechanism are in crucible cast steel, so as to combine strength and lightness. The load is however, excessive for two pairs of wheels, the more so as the length of the overhanging portions involves great variations in the distribution. The load on each pair of wheels will frequently without doubt reach, if not exceed twenty tons.

The regulator and the lever of the vertical action are, as usual, on the right; those of the horizontal action which only comes into action on the steep gradients, are on the left.

The cost of construction of the line on the narrow gauge and with central rail is estimated at £ 300,000; and one which would have allowed ordinary locomotives to be used, about the double; the resources of the State would have caused it to be delayed for a long time further, whatever may be the importance of the line in question.

According to a communication made by Mr *Fell* to the British Association at *Liverpool*, other applications of the system were likely.

A project has been brought forward for connecting the port of *Carwar* in the *Bombay* Presidency (East Indies), with *Gadak*. This line, 135 miles long, crosses two chains of mountains, with gradients of one in 20, for 10 miles.

CHAPTER XV

SYSTEM EMPLOYING LOCOMOTIVES WITH A POINT OF SUPPORT REPLACING THE ADHESION.

434. *Line with a rack.* — The inseparable complication of the adhesion on the side faces of a central rail, the resistances which it involves, and its insufficiency, have led, for gradients much steeper still than those of Mount Cenis, to a return to the primitive idea of towing the engine along by means of a rack. Tried formerly, as we have seen (193), under different shapes, and recently in the United States (419) it has this time been tried under one only, probably the best, for it is the simplest.

In *Blenkinsop's* arrangement, cited further back, one of the rails had on the outside a rack with thick teeth, from 2,00 to 2,75 inches. The two cylinders, vertical, let into the boiler, had their axes in its mean longitudinal plane; the pistons worked by means of gearing, the driving shaft, on which was keyed a toothed-wheel working into the rack.

"Several engines", says *Wood*, "were constructed on this model by *Blenkinsop*, and have continued to be used up to the present time for the transport of coal on the line from *Middleton* to *Leeds.*"

It is not a question of the speed at which these engines ran; it is very doubtful if it was really low enough to warrant an arrangment of the sort, the more so that the weight of these first rough drafts of engines, was very considerable with reference to their power. The adhesion ought thus to have been amply sufficient, even at a very low rate of speed.

Be that as it may, it is evident that these engines presented serious imperfections, from the point of view with which we are dealing: the complete abandonment of the adhesion due to the weight, and the application of the effort on one side only of the engine, at a great distance from its mean plane.

The *Neath Abbey* works (South Wales) had a locomotive constructed in 1836, which deserves to be cited, more particularly as it was a question of an industrial engine intended to work on steep gradients at a very reduced speed, and exposed in that case, to fail in adhesion, at any rate accidentally.

This engine had six wheels all coupled; the pistons drove a special shaft placed behind under the boiler, and which transmitted the motion to the third axle by means of gearing. An auxiliary shaft, having its bearings installed on a frame which could be raised or lowered, carried a pinion toothing at will into a central rack. When lowered, this shaft received, like the third axle, motion from the driving shaft.

M. *Mandet* proposed in 1862, to apply to the driving wheels themselves, outside the tyre, a toothed wheel, which should act only at the points when the increase in the effort of traction should require it, that is to say on the steep gradients, when the rails would be also provided with racks outside; the adhesion would thus always be utilised. The idea of thus gearing into racks, several wheels solidly connected by means of rods, or even only the two driving wheels of an uncoupled engine, seems chimerical. It assumes an amount of precision impossible, not only to realise but to keep up in the gear-work, and it excludes besides all inequality in the distances run by the two sides and consequently curves. It is very probably because he had appreciated this impossibility, that *Blenkinsop* adopted a single toothed wheel; and not being able, or not wishing to place it in the mean plane, with central rail, accepted the drawbacks of the action being placed over to one side.

435. But the towage on a rack implies almost necessarily the central rail, so well adapted to extreme gradients, which alone can, and indeed only in certain cases, warrant contrivances of this kind.

1. *Mount Washington line.* Such is, in effect, the arrangement decided on by an engineer in the United States, Mr. *Marsh*, of *Chicago*, for the little pleasure line which he established in 1866 on *Mount Washington* (New Hampshire), a sort of American Rigi.

The lower station is at 2.700 feet, and the upper at 6.303 feet above the level of the sea. The height of 3.602 feet is gained on a length of 2,5 miles, that is to say with a mean rate of inclination of one in 37, varying from one in 12,5 to one in 3. The workmen engaged in the construction of the line held on with difficulty, as may be imagined, in spite of the spikes with which they were shod. The gauge is 4 ft, 0. After some trials of the *Fell* system, with indifferent success, the engineer decided to apply a rack to the central rail, and to replace the horizontal wheels by one single vertical wheel 2 ft, 5 in diameter with broad thick teeth.

The boiler supported on trunnions, remains always vertical whatever may be the gradient. The engine presents, save in that respect, the greatest

analogy with the Rigi one. Friction rollers, suspended from the frame, and running under the horizontal edges of the central rail, attach the rail to the line, and prevent it rising or leaving the rails.

On the ascent, a strong pawl running over the teeth of the rack prevents all danger of running back. But if it is easy to hinder velocity, it is another thing to destroy it on such gradients. It is thus against the impulse downwards that the most energetic means are necessary. The engine has an air brake, similar to that on the Rigi engine, and a hand-brake acting on the driving shaft, and consequently on the gearing. Moreover, the two vehicles which with the engine constitute the train, that is to say the tender and carriage with fifty places, are, like the engine, both provided with a toothed wheel acting as a brake.

This engine hauls, it is said, the double of its own weight at 4,50 miles an hour.

2. *Rigiline.* — The success of this bold and simple application, determined two able Swiss engineers, MM. *Riggenbach* and *Näff*, to reproduce it under nearly identical conditions.

The Rigi line, worked up to *Staffelhöhe* and to the *Kulm*, permits tourists to make without fatigue the classic but uncertain pilgrimage of the rising sun on that splendid panorama. The starting point is on the border of the lake of *Lucerne*, at *Witznau*, a village which has taken from *Weggis* and *Küssnacht* the Rigi traffic which they have so long had. The line runs up the mountain side, on gradients of one in 4,5, and one in 4, with curves of 200 yards radius, and serves also *Kaltbad* and *Rigi-Staffel*.

From *Witznau* to *Staffelhöhe*, vertical height 3.651 feet.

Length 3,20 miles..	straight....................	2,20 miles
	curves 200 yards............	1,00 miles

Straight at *Witznau* : 50 yards.
Do *Staffelhöhe* : 65 yards.
Maximum gradient, one in 4.
Minimum » one in 15.
Mean » one in 4,6.

At the middle of the line, at *Freiberg* is a crossing and a water column.

The earthworks consist of the cutting above *Witznau*, and the other works of the *Schnur Tobel* tunnel, and the iron viaduct on a curve of 200 yards over the *Tobel* ravine.

The line is on the ordinary gauge, with *Vignolles* rails, 33 lbs to the yard, laid on cross-sleepers, which are tied to each other on both sides by a line of longitudinals bolted down to them L, L (Pl. LXXXII, *figs.* 1 and 2).

It is of the utmost necessity that the road should form a perfectly unyielding framework, offering the most solid support to the rack, any derangement of which might be attended with the most serious consequences.

To counteract more effectually the longitudinal sliding of the permanent way, the cross sleepers, every 82 yards, butt against large stones on end, or against pieces of rail let into solid masses of brick work.

Rack (*figs.* 1 to 4). This is not properly speaking a rack, with projecting teeth, but rather a regular wrought iron ladder; the up rights are rêpresented by two irons *a*, *a*, 0,47 of an inch thick, weighing 41,7 lbs per lineal yard; the rungs *e*, *e*, 3,94 inches apart, are terminated at each end by a turned bearing *f*, (*fig.* 3), not circular in section, so as prevent any rotation, and riveted cold. The portions, 9,84 feet long, are fixed on to the cross sleepers by fang-bolts, and connected to each other by covering plates bolted underneath. At certain distances an angle iron riveted on to the lower face, butts with its projecting web against the upper side of a sleeper.

Spread over such short lengths as 9 ft, 84, the expansion of the rack, during the great heats appears to involve no trouble, in spite of what has been said to the contrary.

The joint is not at the middle of the space between the rungs, but farther from the upper one, in order to insure a sufficient value of the resistance to shearing, along *m n*, *m' n'* (*fig.* 3) brought into play by the thrust of that rung. The rack weighs about 135 lbs. to the yard.

Let us add, in complete of the details of the permanent way, that the engine being unable to move excepting by the action of the toothed wheel on the rack, the latter has to be laid down every where, even on a level, as at the end station of *Witznau*, and *a fortiori* on the crossing on one in 10, laid down midway of the total length of 3,73 miles.

Instead of shifting the rack as well as the points, which would have been complicated, heavy, and scarcely safe, a bridge has been adopted, turning round a centre placed at the extremity of the joint portion, a suitable solution in this case; the train only including in effect, the engine and one carriage, the movable portion has only to be long enough to take those two vehicles. From the smallness of the deviation, the movable rack C, C, joins on conveniently to each of the fixed portions D, E (*figs.* 5 and 6).

436. *Locomotive.* — At *Mount Washington*, the boiler hung on bearing, keeps vertical on all the gradients. M. *Riggenbach* preferred, with reason, a boiler having, as in ordinary locomotives, an invariable position, relatively

to the cylinders. It is thus fixed in its place, and normally to the frame, which forms with the plan of the axles, an angle equal to that of the mean inclination of the gradients, so that the boiler is vertical when on a gradient of one in 5,3. On a line the section of which contains such gradients, a boiler lying on its frame parallel to the permanent way would not do. Its horizontal section, or at least the dimension of that section which projects over the axis of the line, must be as small as possible, to avoid the effects due to change of gradient.

The normal absolute pressure in the boiler is 12 atmospheres.

The four wheels, which simply carry, are loose on their axles. The curves of 200 yards radius are thus easily passed through, in spite of the parallelism of the wheels, which are 9ft, 84 apart.

The pistons, 10,64 inches in diameter, with 15,75 inches stroke, work the motor shaft A (*fig.* 8) by outside cranks, transmitting the motion to the driving axle B by two pinions p, p, 8 ins, 82 in diameter, and two wheels r, r, of 2,09 in diameter. The sole driving-wheel M, keyed on the middle of B, enlarged, is 2 ft., 09 in diameter. The motor shaft B is supported like the leading axle, by carrying wheels loose on journals outside the frame.

Let us remark, in passing, that this general arrangement answers to the program of the Rhenish railway (199), by keying the wheels on their axles, coupling them, and suppressing the central wheel and rack.

Carriage. The carriage, represented by *fig.* 11 and 12, has an outside frame, and the wheels keyed on the axles. The engine is always below the carriage, to which it is not coupled, and which can always be stopped independently. This independence, special in the case of extreme inclines, is a valuable safer-guard.

The engine full weighs 12 tns, 5; the carriage weighs empty 4 tons, full about 8 tons, and contains 54 places. The engine thus hauls the two-thirds of its weight, at the speed of 3 miles an hour. The trip from *Witznau* to *Rigistaffel* lasts one hour and five minutes, both up and down.

437. *Means of stopping.* — On such gradients, the main point is the application of means of stopping of absolute certainty; ordinary brakes acting by means of the friction due, at the limit, to the weight of the vehicle, are thus powerless in stopping, just as the adhesion is for the traction. And the point of support for stopping is naturally the same as that for the traction, that is to say that is taken on the rack.

The means of moderating and destroying velocity are numerous.

1. On the leading axle of the engine is keyed a toothed wheel similar to the driving wheel M; on each side of this wheel is keyed a pulley presenting several grooves and on which the driver presses with more or less force by means of the handle n, and of the bell cranks p, q, r, t, u, on to shoes s, s', provided also with grooves which enter into those of the pulleys.

It is thus an application of the conical gearing (214), a very logical application when the object is, not to avoid passive resistances but on the contrary to develop very considerable ones.

2. The shaft A of the pinions which drive the motor-axle carries keyed on its middle, a similar pulley ω (*fig.* 8) but of smaller diameter, on account of want of room, and which, powerfully locked between grooved jaws, locks the driving wheel by means of the gearing.

The two brakes of the carriage (*fig.* 11) are exactly similar to those of the front axle of the engine; they allow the wheels to be locked, and with the toothed wheel; locking means stopping.

These hand-brakes besides only serve regularly for the stoppages at the stations. As to the speed on the descent, which is the same as on the ascent, it is regulated by the velocity of rotation of the driving axle B, and consequently by the velocity at the circumference of the driving wheel M, equal to the velocity of translation; and naturally, the mechanism of the motor itself is employed for that purpose. But in this case, counter steam is not had recourse to, but compressed air. The regulator ρ is closed; the slides being reversed, the air drawn in by the pistons during the communication with the atmosphere is driven by them into the induction pipe l, l, and forced back into the atmosphere, through an opening more or less throttled by means of the cock K. On the exhaust pipe t, t, is placed a case Q pierced with two openings a, b provided with valves connected together by a lever l, in such a manner that one of the openings is shut when the other is open. When running with steam, that is to say on the ascent, a is raised by the steam which escapes, and b is held down on its seat. When running in the contrary direction and without steam, it is the reverse; so that the pistons draw in, not the hot gases bringing over with them solid matters, coming, through the tube t, from the smoke-box and the chimney, but air coming directly from the atmosphere, through the opening b (*).

The brake in question is nothing else indeed, than that of M. *Debergue*,

(*) According to the account published in the *Mémoires des ingénieurs civils*, by M. *Mallet*, whose visit to the Rigi line was later than mine, the self action of these valves was not quite satisfactory, and they are now worked by hand.

applied to, amongst others, the locomotives of the little branch from *Enghien* to *Montmorency* (419).

The effect of gravity is employed not only to compress the air, but also to heat it, and with it, the cylinders and the pistons; a small jet of water taken from the tender, and directed during the running in question into the hollow of the slides, counteracts the heating, and gripping of the parts.

We shall return with the necessary details to the nature and use of the means of stopping possessed by the ordinary locomotive. But it was indispensable to say a few words on the subject on the present occasion, in order to give a complete idea of the rack system. We see that the distribution runs always in the same direction, on the ascent and on the descent; it is by the very fact of the retrograde movement that the reverse action of the slides is established.

The means of moderating and of destroying the velocity, applied to the engines and carriages of the Rigi, are powerful. They are sufficient, absolutely, but on condition that there be no breakage. If a tooth of the wheel were to break on the descent, would not the shocks involve other fractures of those organs, the last sheet anchor of safety, and the acceleration, terrific on such gradients, could it be mastered?

It is certain that if the strangeness of the conditions under which one is placed on this locomotive, climbing literally up the ladder, produces at first a certain impression of mistrust, reflection calms it, and the eye gets accustomed to the position; the independence of the locomotive, and of the carriage which is sufficient in itself, as to means stopping, is very reassuring.

But there remains however, a *desideratum:* it is that every thing does not rest definitively on the teeth of the wheels of the carriage and on the rungs of the ladder; that their fracture, scarcely probable, althoug possible, does not render the means of stopping powerless.

The rack forms really a central rail, solidly constituted and the side faces of which are adapted for the application of a jaw brake, analogous to the Mount Cenis one. Horizontal rollers similar to M. *Fell's* (424) and running along the webs of the should be thicker] irons, seeme qually preferable to the hanging rods θ, θ. (Pl. LXXXII, *fig.* 5), as a security against running off the line and the lifting of the engine, in the case of the rack being obstructed by an obstacle. The projection of the cup headed rivets of the rungs would evidently be no objection to the application of shoes or rollers on the faces on the rack.

438. I do not hesitate to look on the rack engine as far preferable, in principle, to *Fell's* system, especially if it could profit, at need, by the adhesion due to the weight. The rack gives more simply, and if it be desired, with as much security, much more than the adhesion on the central rail gives. But it seems impossible to apply to the progression of one vehicle, two, or *a fortiori*, several toothed wheels worked by the same mechanism. M. *Agudio* has done it for his new gearing *locomotor* (465), but under conditions which seem irreproachable, the toothed wheels being independent the ones of the others, or at least their solid connection having for limit the friction of the cable over a pulley, only half the circumference of which it embraces. Imperfections which with several wheels simply adhering, only involve slipping, are evidently quite another thing when it is a question of toothed wheels.

The dimensions of the teeth being limited, the effort of traction is so as well, by that very fact, with a single wheel.

The central rack allows besides of curves, and nothing would hinder these being of smaller radius than on the Rigi, on condition of taking into account the convergence of the rungs, as has already been done with curves of 200 yards, in which it is handly perceptible in the length of 9 ft,85; but the working by rack would not permit of such steep curves as those on Mount Cenis. Besides the engine of the Rigi is always on the rack: it can only move on that condition, because its carrying wheels are loose; and although it does not seem impossible for the engine to quit the rack and take on to it again, running at a very low speed, it is certainly less easy, and has not yet been done.

439. *Ostermündingen railway; locomotive for two purposes.* — A first trial has however been made in that direction. M. *Riggenbach* has connected to the *Berne* and *Thun* line, a neighbouring quarry, by a line composed of two pieces of level and an intermediate gradient of one in ten for 550 yards (*); the rack simpler and lighter than the Rigi one, only exists on the incline. On the levels, the progression is effected by the adhesion of the hind wheels. At each end of the incline, the rack is prolonged horizontally for 10 feet; the prolongation being movable vertically by means of four excentric rollers which support it, and which can there be lowered by an amount a little more than the height of the teeth of the wheel. An

(*) Société des ingénieurs civils of *Paris*. Meeting of 20th Oct. 1871. Report by M. *Mallet*.

engine coming either for ascending or descending, finds the corresponding length of rack let down; it stops above this, and the simple manœuvre of a lever brings up the length to its level and lets teeth in between the rungs, with perhaps a little trying in the case of one of the former coming against one of the latter.

The engine has an ordinary boiler, with very short tubes; the incline, little steeper than that on Mount Cenis, allowed the boiler to be kept parallel to the frame.

As at the Rigi, the driving rods impart motion to a shaft which transmits it by gearing, to another on which is keyed the towing wheel, but which carries no weight. The first shaft can also by means of ordinary coupling, impart rotation to the hind bearing wheels which it drives directly, that is to say without gearing, their diameter (3 ft, 77) being sufficient. A clutch apparatus allows this second transmission to be brought into play only on the points, where the rack is not laid. Considered as an ordinary engine, working by adhesion, this one in question thus belongs to the category of tank-engines fourwheeled, and with intermediate driving shaft (251); but the latter does not cease driving the shaft of the towing wheel, which thus turns free.

In order that the adherent wheels and the towing wheel may act simultaneously, that is to say in order that their velocities at the circumference may be equal, it would require that the ratio of the gearing which drives the second should be the same as that of the diameters, or:

$$\frac{3{,}77 \text{ feet diameter of the adherent wheels}}{2{,}50 \text{ feet diameter of the towing wheel}} \quad \text{or } 1{,}5.$$

Now, it is very nearly double, and as is necessary to have, on the incline, both a very low speed, and a suitable velocity of piston.

The independence allows, in a word, to give the two categories of wheels, diameters which correspond for the same velocity of pistons, and at a very low speed when the effort is very great, that is to say on the incline, and at a reasonable speed when the effort is small, that is to say on a level. Thence the necessity for the clutch, instead of a fixed connection by rods of the intermediate shaft with the hind axle.

440. Some engineers, fearing lifting in the case of a tooth of the wheel striking against an obstacle which might have got in between the teeth of the rack, would prefer that wheel to be keyed not on an axle, but as in the *Ostermündingen* engine, on a special shaft, which a vertical play regulated by

a spring would allow to rise a little without exposing the engine itself to rise. But the arrangement adopted at *Mount Washington* and the Rigi, is so simple that it ought not to be given up without well ascertained necessity.

These installations have a certain interest; they would probably solve the question in favour of the central rail with gearing, compared to the central rail with side pressure wheels, were it not for the curves. But the mode in question does not seem to us to have any higher bearing; that is to say that the simplification which would result therefrom, were it sanctioned by practice, could not render the principle applicable to great lines, which always obtains only a very reduced amount of useful effect from the motor, tolerable only at extremely low speeds; which inflicts excessively on the working, and would be at the same time altogether incapable of any serious traffic. The *Fell* system besides, adapts itself better to the cases where, on account of uneveness in the trace either on plan or section, the central rail is not necessary on the whole length.

Be that as it may, the Rigi line is certainly remarkable, by the boldness of the principle and by the merit of the mechanical execution; and the originators never dreamed as has been made out, of proposing a locomotive hauling itself up one in 5 and one in 4, as a solution applicable to the crossing of great chains of mountains by lines of great traffic (*).

At the Rigi, a mass of tourists will no doubt be regularly attracted, great enough to render the operation remunerative. This singular specimen is

(*) It was so at the outset. But pretensions have since enlarged. At the 27th meeting of the Engineers at *Zürich* (1st oct. 1877) M. *R. Abt* an engineer at *Aarau*, and collaborator of M. *Riggenbach* took on himself to repudiate the modest part hitherto accepted by the rack-system, and to present it as the true solution of the question of traction on steep gradients, even on the great lines.

As the critical position of the approach lines to St Gothard is at this moment (1878) the object of attention on the part of all those who are studying that difficult problem, it is not in this case the excessive gradients of the Rigi which have to be dealt with, but only one in 20 or one in 16,7.

There are no grounds for the rack, unless the velocity adopted is lower than that for which the adhesion is sufficient. Will this velocity so reduced permit the requirements of the traffic to be satisfied? Admitting that it will, let us remark that if an engine can have only one towing wheel, nothing hinders the trains being multiplied, and that the rack is in itself a very safe means of spacing the trains, and dispatching them at very short intervals.

The available effort of traction benefits by the whole of the reduction of the speed; but a portion of this benefit is absorbed by the resistance incidental to the additional organs, and among others by the friction of the teeth, estimated by M. *Abt* at from 3 to 4 per cent of the effort of traction.

Here we find again appearing the pretention already put forth by the partisans of supplementary adhesion by lateral pressure on a central rail: that of a very notable reduction in the dead weight of the engine, referred to the amount of work available.

" While engines working by means of adhesion require " says M. *Abt*, " a weight of $\frac{1}{5}$ th of a

in itself a further attraction, especially if there be some appearance of danger, without the reality. Perhaps indeed a little of the reality would do no harm, provided there were not too much of it. But it is hardly to be seen to what other circumstances this system can be applied. The Rigis are rare; and as to the purely industrial freights which might have to be carried on such gradients, so costly a mode of traction could never stand comparison with stationary engines and cables. The *Ostermündingen* trial had doubtless for object, not a solution applicable to permanent working, but only the completion of the study of this mode of traction. The engine has only to draw up empty waggons, but that is an argument the more, in favour of the engine with a cable and automatic plane.

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ton per horse power at the Semring, $\frac{1}{7}$th of a ton at the Ütliberg, the rack-engines only require a weight of $\frac{1}{10}$th to $\frac{1}{11}$th of a ton per horse power."

Admit, again this fact. But what is the cause of this relative lightness] which M. *Abt* entitles, not without reason, " surprising " ?

It is not, apparently, the rack, that is to say the supplementary organs which it involves!

According to M. *Abt*, this lightness is derived from the indirect transmission of the motion of the pistons to the driving shaft, that is to say from the great speed and small mass of the parts of the machinery. But what hinders, if this be so, the same principle being applied to slow engines with adhesion, and letting them profit equally by the lightness thus acquired, they say, by the rack-engines?

But, in reality, it is elsewhere (partly in the small diameter of the wheels) that must mainly be looked for, the very complex causes of the low relative weight of the engines constructed for working on a rack.

Without discussing here this question (it is not the place) let us point out one element of lightness, which M. *Abt* does not seem to have remarked : which is that the rack excludes a cause, very serious at times, of improductive expenditure of steam, namely slipping. Hence, the neeessity of storing up in engines with adhesion working close to the limit thereof, and subject therefore to slipping, an excess of steam which reacts on their weight; it is necessary to take this into consideration, but without exaggeration.

A line with gradients from one in 29 to one in 16,7 seems to be suitable to the ground in the valleys of the Reuss and the Ticino, so unmanageable from the point of view of a development with moderate inclines : a development possible only by the adoption of the horrible expedient of vertical helices!

On such gradients, no one doubts that if the locomotive is, rigorously speaking, economically to be tolerated, it is only on condition of very low speed, 3 miles an hour for example, and hence by towing itself along a rack. That is, and nothing more, what MM. *Riggenbach* and *Abt* can say and maintain. M. *Riggenbach* himself declares that the inclination of one in 14, is the limit for the rack-engine; " die Sicherheit ", says he, " ist zwar auch dann noch ebenso gross, allein *die Leistungfähigkeit ist eine viel geringere* " (*a*). Such a gradient is, certainly very exaggerated; and M. *Hellwag* admits only $\frac{1}{22,2}$.

But if speed of 3 miles is much too low, if speeds of about 9 miles an hour are desired, what is the use of the rack, seeing that the adhesion is then sufficient?

(*a*) Letter to M. *Hellwag*.

It is a question, at the Rigi, not of continuous working, but of an annual period of activity during some months. As soon as the hoar frosts arrive, and there they are early, people are off. In 1872, the service opened on the 9th of May, and continued up to the first days of October; but it was only really active during the period from June to September. Fixed mechanical arrangements, especially pulleys for supporting a cable, left to themselves under the snow, would undergo serious depreciation; while the locomotives resume their service after some months, rest in the shed, as if nothing had happened.

The experiment of the Rigi is not only curious, but is, also, well considered; it is however applicable under conditions unique, or nearly so, and is on that account of only secondary importance, apart, of course, from the interest always attached to the solution of any problem of practical mechanics.

The line had not been completed, when a rival company was already got up for the construction of a line from *Arth* to the *Kulm*. In the terms of an agreement (the settling of which was more trouble than of many a great affair), the new line was to join the old one at *Staffelhöhe*, and from that point to the *Kulm* one single extension.

An other town in America, *Pittsburg* (Pennsylvania), also has its *Mount Washington* line, a little pleasure railway intended to bring into value the ground on a hill. It is 223 yards long, and rises 531 feet; inclination one in 2. But in this case rope traction was simply adopted. The carriages have their frame horizontal on the incline.

441. *Various systems.* We shall only say a few words on the other contrivances founded on the same principle, that of a point of support replacing the adhesion, and which have not been subjected to any solid tests, which they would very probably be unable to stand.

1. M. *Wetli* has proposed (*) a system founded also on gearing, but freed in part from the passive resistances inseparable from ordinary gearing (Pl. LXXXVI, *figs.* 21 and 22). The principle is not new: it is that of the helicoidal gearing of *Hook* or *White*, the object of which is to greatly reduce the friction between the teeth, and in which as is known, the component parallel to the axes of the wheels, is destroyed by the opposition of two systems of teeth, inclined in contrary directions. In the present case, one of the teeth becomes fixed, and its radius infinite, that is the rack; its two systems of teeth are re-

(*) *Grundzüge eines neuen Locomotiv-system für Gebirgsbahnen*. Pamphlet. *Zurich*, 1868.

placed by two systems of straight lines a, a, a, a', a', a', inclined in contrary directions, forming a series of chevrons laid between the rails; the bearing wheels run on these latter, while the wheel or rather the moving drum R, R, with symmetrical helicoidal teeth h', h', placed between the rails takes on to the successive chevrons, which cross somewhat, so that the helices may be already in gear with one chevron before they have left the preceding one. The increase of cost, compared with a simple rack would be probably out of all proportion with the reduction of friction, were such real; but, under the conditions in question, it is quite theoretical. The line would have besides no teeth, that is to say chevrons excepting on very steep gradients; every where else the engine would act by the adhesion alone of its carrying wheels. The principle of the system admitted, there would still remain many points to be discussed. A preliminary trial has been made on a short piece of 1.327 feet running out the *Wadenschwyl* station, on a gradient of one in 20, and curves one of which has a radius of 980 feet. The tank-engine has three axles, the two end ones with wheels 2 ft, 91 in diameter, the intermediate one supporting the drum with helicoidal threads. Heating surface, 495 square feet; weight of the engine, with a small amount of supplies of 0 tn, 6, 20 tons, the toothed wheel entering for 2 tons into this figure.

It was feared that the screw would not be able to be coupled with the carrying wheels; M. *Wetli* did not share those fears, and the experiment seems to show that he was in the right.

With the three axles coupled the engine drew 60 tons not including its own weight. The small production of the boiler only allowing of a very reduced speed, it was necessary to lessen the load by $\frac{1}{3}$, in order to get 9 miles an hour.

The motion was effected at the same time with great steadiness, without the slightest shock between the threads of the screw, and the rails in chevrons. The starting was very easy.

A very simple mecanism permits the screw to be raised, and to be put into action again without stopping. Raised, it continues to turn in solid connection with the wheels, but without doing any work.

It is the same thing on the portion of the line without chevron-rails.

When the driver lowers the cylinder, which is done by simply letting it go, he evidently cannot hit on the point where the two systems of projections of the wheels and of the rails have conformable positions; but as soon as the adhesion of the carrying wheels is insufficient, slipping takes place and the drum gets into gear with the chevrons.

On the descent, an air-brake acting on screw, regulates the speed, without the necessity of having recourse to the brakes of the passenger carriages.

Although the chevrons were made out of old rails, the wear of the threads of the screw was very small.

Altogether the experiment seemed favourable to the principle. A commission formed principally of professors of the Polytechnic at *Zürich*, had no hesitation in declaring the *Wetli* system very superior to the ordinary rack. The line from *Wadenschwyl* to *Einsiedeln* was in construction, three powerful engines were on the point of being delivered, when a catastrophe occurred that compromised the success which was already looked on as attained. On the descent of a trial train, the threads of the drum suddenly left the chevrons, and the train smashed itself at the foot of the incline.

The repetition of such accident can doubtless be prevented, and the system placed in satisfactory conditions as to safety; but whatever may be done, it will not escape, like the rack itself, which is at the same time much simpler, from the objections raised against the locomotive put to work on very steep gradients.

2. MM. *Grassi* and *Tubi* have sought for the solution of the problem in one of the most used mechanical powers, the screw, an organ which now-a-days more than rivals paddle-wheels in the propulsion of vessels; in which case the water itself forms the nut.

The machinery of the locomotive imparts a movement of rotation to a cylinder, hung from the frame parallel to the permanent way, and carrying a screw with a square thread. The difficult point is the constitution of the nut. A sort of socket enveloping a portion of the cylinder, and running the whole length of the line would be infinitely too expensive. The inventors replace it by rollers with fixed axes normal to the plan of the line, having the pitch of the screw for diameter, and laid down at such intervals as allow it always to be in gear with one roller at least on each side.

In its double movement of rotation and of progression, the screw imparts to the rollers on which it rests, a movement of rotation, so that the sliding friction is brought on to their axes, and its work reduced in consequence.

3. An English engineer, Captain *Moorsom*, who investigated this system, accepted it in principle, the difficulties of carrying out according to him, being such as can be overcome. This is really optimism, in the face of such enormous resistances. So as not to exaggerate the velocity of rotation of the screw, it would be necessary to give it a long pitch, which would have the contrary effect of exaggerating the component, transversal to the axis of the line, of the reaction of the rollers on the screw. There are besides

many other objections; the rollers resisting by their inertia, do not turn immediately, and act at first as if they were fixed. The inventors had thought of giving them previously a movement of rotation, before they were reached by the screw; but that only removed the resistance from the screw to the part which should thus precede it. Sharp curves would require a short screw, and consequently multiplied rollers; and these local conditions would affect the whole line.

After some experiments made at *Turin* on a sample 200 feet long on one in 20, the Italian commission (*) concluded that the principle is not one of those which it is possible to take into consideration for the solution of the problem of the crossing of the Alps. It is difficult to arrive at any other opinion.

442. *Locomotive acting by the intermedium of a cable passing over a return pulley.* — If such expedients as the central rail and rack, are admitted, the locomotive is rigorously possible on gradients of one in 12,5 with the first, one in 4 and even more with the second; but in spite of the diminution of velocity which allows the increase thus obtained of the tangential effort on the driving wheels, and consequently of the increase of the effort of traction which results, the smallness of the useful effect and the impossibility of carrying on a considerable traffic, limit the application of these means to some particular cases, of quite secondary importance.

As to the locomotive pure and simple, that is to say acting by the adhesion due to its weight, we have seen by the examples given above (chap. XIII) on what gradients progressively increasing, and looked on at first as impossible, it is made to run up now-a-days.

It is necessary that we should come to an understanding as to this generally admitted and, formerly, very real impossibility. As the first engines, with not very high pressure, were not very powerful, and were relatively heavy, they could only have hauled, on very steep gradients, one in 40 or one in 33, for example, loads absolutely insignificant. If we succeed at present in utilising (at what a cost too!) the locomotive on such inclines, and even steeper, it is in no way on account of the discovery of any new principle; it is simply thanks to the increase of the absolute power of the engines, and of their greater relative lightness, results obtained by simple improvements of detail. Formerly, engines could barely take themselves up one

(*) *Ferrovia delle Alpi Elvetiche*, etc. — Vol. I, page 314.

in 20. The old line from *Andrezieux* to *Roanne*, which on one part of its distance quitted, for economy's sake, the valley of the *Loire*, had gradients going up to one in 20, on both sides of the *Neulize* ridge. This part was the great difficulty in working this line, most uneven, and offering samples of all known modes: horses, locomotives, stationary engines with rope. In 1854 it was thought of substituting the locomotive for the stationary engine at *Neulize*, but the locomotive acting by its weight as well as by its power. The summit being exceedingly narrow, the engine had to run down the one side, drawing the train up the other by means of a cable. But this manner of utilising the locomotives of the company was obliged to be given up, "seeing that", says M. *Bousson* (*), "once down, they could not easily get up again". This was sufficient to condemn the special application in view. But the principle itself can scarcely bear examination. In traction by stationary engine and cable, it is not the stationary engine which gives rise to objections, but the cable; and as long as this is adopted, there is nothing better to do than to accept also the stationary engine.

The locomotive has against it its dead weight, the influence of which on the useful effect increases rapidly with the inclination; the cable has against it passive resistances which are the more serious the longer it is, the sharper and more numerous the curves, seeing that all the resistances acting along the whole length of the cable have to be overcome at one time.

The locomotive has the advantage in this respect, as the resistances due to curves act successively.

In the course of a discussion on the *Agudio* system, which we shall soon come to (455 and foll.) by the "Société des Ingénieurs Civils" at *Paris*, some members sought to establish that there would be an advantage in suppressing stationary engines, and consequently the moving cable, keeping simply the adhesion cable along which the locomotive would tow itself, taking the place of the locomotor. This is falling back on a variation of the system of locomotive and central rail. Equivalent, from the point of view of the traction, to the central rail, the cable may, in effect, be preferable, in certain cases for small industrial planes.

But if it were desired to employ the locomotive and the cable simultaneously, it would be much better without doubt to apply the principle tried at *Neulize*, that is to say the engine ascending alone, and descending the other

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(*) *Mémoire sur le choix des moyens de traction pour le chemin de fer d'Andrézieux à Roanne.* Pamphlet in-8°, 1854.

side or on a parallel line on the same side, and drawing the train by means of a rope passing over a pulley, on the summit. The cable with direct traction being adopted, with the expenses and disadvantages it involves, the stationary engine seems certainly preferable. But, in fine, if the locomotive were desired to be retained, under that form at least, it would utilise at once both its power and its weight, and it would have what it fails in, with every other combination, on steep inclines, a useful effect.

This combination of the locomotive and cable has been long in action on the one in 30, 1,55 miles long, on the *Dusseldorf* and *Elberfeld* line (414 and Pl. XCII, *fig.* 3).

The installation at first included a 40 horse stationary engine on the summit, with an endless rope, to which were attached at the same time an ascending and a descending train.

"They were not long in discovering", says M. *Lechatelier* (*), "that the effort developed by the stationary engine could be dispensed with, and that it was sufficient to let the locomotives work at the head of the trains, one ascending, the other descending".

The endless rope was replaced by one with two ends; the two lines are thus alternatively occupied by ascending and descending trains. The locomotives, which balance each other, act by their power only, and not by their weight. But extra trains, that is to say coming from *Dusseldorf* without crossing on the plane, are drawn by the aid of the auxiliary engine, which is permanently kept on the summit; it fastens on to the descending end of the rope, and utilises thus its power and its weight, according to the principle tried at *Neulize*. As to the extra trains from *Elberfeld*, they descend by means of brakes and counter-steam on a third line set apart specially for them.

This method of working the line is still in force (**).

443. Let us return to the locomotive working under normal conditions, that is to say hauling or pushing the train directly. It is, as we have said, very desirable not to exceed one in 40. Steeper inclines in no way invalidate, on the contrary, this opinion, to which experienced engineers are coming more and more. It is precisely the experience of what steep inclines cost, which has brought up this reaction against them.

As far back as 1845, M. *Bousson* had constructed for the service of one of

(*) *Chemins de fer d'Allemagne*, 1845, page 115.
(**) *Handbuch*, etc. Vol. I, page 701.

the gradients of the Loire line (the *la Renardière* incline 874 yards long, on one in 33, with continual curves and counter curves of 328 yards radius) locomotives with six wheels coupled, 3 ft, 6 in diameter, 550 square feet of heating surface, wheel base 6 ft, 56, weighing full 17 tons; these engines drew, beyond the 7 tons tender, 6 or 7 waggons weighing 34 tons; but they would have been quite incapable of drawing the same load up a longer gradient; the pressure rapidly lowering.

Under the same conditions of ground, the limit of the inclines should be the less, the greater the importance the traffic has or is likely to have. This is what the partisans of mechanical expedients lose sight of, who reduce the problem to the proportions of a simple lift, so to say. The question is, altogether, to know not what is, in general, the practical gradient limit for locomotives, but what is in each case the limit it is expedient to adopt.

If profound study of the case proved the impossibility of keeping within this limit of about one in 40, for long inclines, the line ought to be laid out over again with a view to the application of fixed motors. The trace of the line is essentially connected with the method of working it, and this new investigation would result very differently, and, particularly, in steeper gradients. Admitting then from one in 40 to one in 33 as extreme limit for long inclines for locomotives, does not mean that, from such limit out, the fixed motor should come purely and simply in the place of the locomotive, on the line as laid out for the latter. There would generally be a considerable difference between the highest rate of inclination in each case.

When it is found that the locomotive cannot do all, its field of application must be extended, if the ground permits, as far as possible under the conditions suitable to it, that is to say, rising moderately, and then surmounting by recourse to stationary engines, the obstacles thus accumulated.

The question of gradients and the comparison of the different modes of traction have been studied with care by the technical commission instituted by the Italian government with a view to the crossing of the Swiss Alps (*). The principal conclusions of the report deserve to be quoted :

" Inclinations of one in 33 ought to be admitted only as quite exceptional; in long tunnels, they should not exceed one in 45 to one in 40. From one in 40 to one in 33, the working expenses increase in a considerable propor-

(*) *Ferrovia delle Alpi Elvetiche.* Vol. I. — Report of the commission charged with the technical examination of the projects and studies relative to the passage of the Swiss Alps. (*Rapporto della commissione per l'Esame tecnico*, etc....) *Firenze*, 4to. 1866, *Totani.*

tion, and there must be well founded advantages from the point of view of construction, in order to accept this latter limit ".

The commission pronounces against the suppression or the reduction of long tunnels, obtained by an increase of elevation of from 1.970 to 2.300 feet; it admits this for temporary lines, but not for the definitive trace of great lines.

It considers at the same time as only executable by ordinary method, tunnels which do not require shafts more than 985 feet deep.

As to shunts, the commission does not reject in an absolute manner this means of developing the line, so as to avoid too sharp curves, but insists on the drawbacks thereof: it objects to these that they require crossings, special lines for the engine to take off and go in front, turn-tables, tedious operations, and so on.

All this can be vastly simplified by double traction, with one engine behind; but a more serious objection is, that it would be almost indispensable that a station on the horizontal should be placed at the reversing place; which would often be very difficult and very costly, under the conditions of configuration precisely supposed by the adoption of such a means.

The *St. Gothard* projects, on the one hand M. *Wetli's*, on the other MM. *Beck's* and *Gerwig's*, included spirals, or rather vertical helices; an extremely costly means, already proposed by M. *Pressel* for rising up through the *Ticino* and *Reuss* valleys.

So only these projects limited their inclines to one in 40 and one in 38,5.

444. *Examples of altitudes reached by locomotives lines.*

Line de *Cerro* from *Pasco* (Peru, Corderillas)	14.200	feet
Line from *Vera Cruz* to *Mexico*	8.038	»
Rocky Mountains (*Sherman's* Peak, Pacific line)	8.005	»
Tunnel of the Sierra-Nevada (Pacific)	7.044	»
Mount Cenis (*Fell's* temporary line)	6.972	» (*)
Brenner (*Verona* to *Innspruck* line)	4.485	»
Copiapo extension (Chili)	4.472	»
Canada tunnel (crossing of the Guadarrama)	4.462	»
Great tunnel through Mount Cenis (middle)	4.249	»
Lioran (*Murat* to *Aurillac* line)	3.780	»
Madrid to *Saragossa*	3.671	»
Great Western of New South Wales	3.658	»
The Loges tunnel (*Neufchâtel* to *Locle*)	3.438	»
Alais and *Brioude* line (Ridge of *la Bastide*, Cevennes)	3.376	»

(*) This line will ultimately go to 6.627 ft.

Madras railway (*Bangalore* line).	3.350 feet
Santander to *Alar del Rey* (Pyrenees). *Pozazal* ridge	3.229 »
Marseilles to *Gap*	3.169 »
Line from *Mouchard* to *Neufchâtel*. Passage of the Jura	3.084 »
Semmering (Norian Alps. — Tunnel)	2.897 »
Santiago to *Valparaiso* (Tabor incline)	2.641 »
Baltimore to *Ohio* (Alleghanies)	2.624 »
Norwegian lines (Scandinavian Alps)	2.257 »
Bhore Ghât (East Indies)	2.027 »
Otzaurte Peak (Pyrenees). Northern of Spain	2.514 »
Crossing of the Grampian Hills (Scotch lines)	1.486 »
Crossing of the Apennines. Line from *Turin* to *Genoa*	1.184 »

CHAPTER XVI.

TRACTION BY STATIONARY ENGINES.

§ I. — **Rope acting by direct traction.**

445. The work of the motors can be transmitted to the train either by a rope, or by the elasticity of the air.

The rope, acting by direct traction, is the simplest means in appearance, but has serious drawbacks.

Almost entirely given up now-a-days, excepting for purely industrial lines, it was formerly adopted in certain cases, even on grounds independent of the gradients. Thus the locomotive was at first interdicted on the *Blackwall* railway with gradients of only one in 100; this line passes through, on level of the roofs, a most populous part of *London*, and fires were apprehended.

Between the two modes of traction : locomotive and stationary engine with rope, as to what concerns the practical limits of their application, there is a sort of antagonism which it is well to point out here at once. For the locomotive, the element which is especially limited, is the inclination; for the stationary engine, it is the length. Whatever be the intermedium employed, it involves of necessity losses of work, increasing with the length, and which beyond a certain point would place this mode of traction under conditions as to useful effect quite as unfavourable as those of the locomotive working on gradients of excessive steepness.

The question of length is thus put for the stationary engine, as the question of inclination for the locomotive; whence the necessity of dividing the trains, beyond a certain limit. Without doubt, the length of the gradients is by no means indifferent for the locomotive itself. It would be an error to believe that, as long as a gradient has to be run over with a uniform speed, the length matters, little more or less. On a steep gradient, the evaporation and the combustion must be actively pushed on. If this strain be kept up, the grate gets choked, and it becomes more difficult to keep up the fire and the steam. The influence of the length, although very real, and variable at the same time, is thus indirect, and of quite another nature than in stationary engines.

The automotor system is frequently applied on inclined planes serving for carrying industrial freights. It is the more suitable for these, as the load is generally downwards, so that the ascent of the empty waggons is af-d with very little cost.

The same principle is usefully applied also to inclined planes for passenger-traffic, where the gradient is very steep, and the traffic very active. The dead weights being entirely in equilibrium, and the useful loads more or less completely so, the motor has only to furnish a certain amount, especially for overcoming the passive resistances.

446. *Croix Rousse, Automotor plane at Lyons.* (Pl. LXXXIV, *figs.* 9 and 10). This plane connects the *Croix Rousse* with the quarter of the *Terreaux* which is 230 feet lower. Its length is 535 yards and its inclination one in 6,52. It has two lines of rails, each serving alternately for the ascent and the descent. The cable with two ends, winds on, on one side, and unwinds on the other, on an upper drum, which the engines drive first in one direction and then in the other.

The power of the engines was determined by MM. *Molinos* and *Pronnier*, the engineers, on the following bases:

	Tons
1st. Parallel component of the weight of the load (300 passengers at 0 tn, 07 : $300 \times 0{,}07 \times 0{,}1605 =$	3,370
2nd. Rolling resistance of the ascending train (3 large carriages with two stories and 108 places, weighing 12 tons empty); weight of the train, 36 tons + 21 = 57 tons : normal component, 55 tns, 85 resistance at 0,005	0,2790
3d. Rolling resistance of the descending train, 0 tn, 035 : normal component 0 tn, 03528, at 0,005	0,1760
4th. Parallel component of the ascending line of the rope, 1.476 feet long at starting, and weighing 17 lbs, to the lineal yard	0,6140
5th Rolling resistance of the pulleys supporting the cable : Load : $0{,}450 \times 85 \sqrt{1 - 0{,}1605^2} = 3{,}710$ tons. Allowing 0,005 for rolling resistance of the pulleys to rolling	0,0188
Total maximum effort	4,4578

At the regulation speed of 6 ft, 56 a second, the effective power of the engines ought thus to be 119 horse; it has been carried to 150, to make up for the stiffness of the rope brought into play on the drums, and also on the return pulleys, which the local conditions rendered necessary, the want of space at the top of the plane having obliged the engines to be placed at the side of the line (*fig.* 10).

The stock employed in 1872 included three categories of passenger carriages and trucks for carts :

	1ST CLASS	2ND CLASS	WEIGT EMPTY
	places	places	tons
Composite carriage for sunday traffic...........	24	60	8,528
Second class do................................	0	100	8,073
Composite do. weekdays.........................	12	80	8,073

For the carriages, as well as for the cart-trucks, the frame and wheels weigh 6 tns, 588; for low sided trucks, a flooring and two partitions have to be added, weighing 1 tn, 10, or altogether 7 tns, 688.

A cart harnessed, weighing 1 tn, 50, and with a load of 4 tns, 50, represents thus, with its two horses weighing 1 tn, 4, a total weight of 15 tns, 088. The composite for week-days with 92 passengers weighs 14 tns, 60; the maximum weight of a train, formed of either two carriages, or of a carriage and a truck, is thus very nearly 30 tns, 00.

The drum is 14 ft, 76 in diameter. To prevent the spires of rope from fouling each other in winding on, the rope is guided by a traveller moved by a screw, the movement of which is connected with that of the drum, in such a way, that for one turn of the latter, the traveller advances, parallel to the axis, by the diameter of the rope plus a little play.

The stationary engines have 2 ft, 23 cylinders with 6 ft, 56 stroke. The distribution of the steam, by slide-valves, only serves for changing the direction, the distance being too short for the application of a variable expansion, in spite of the variation in the amount of work to be done.

Brakes. The automatic jaw-brake applied for the first time on this incline is the most interesting and most characteristic feature of the *Croix Rousse* plane (Pl. LXXXV, *figs.* 1 to 4).

The brakes can be worked by hand, but the necessity for this scarcely occurs, and their function is particularly to insure automatically, in case of the rope breaking, the almost immediate stoppage of the train, either ascending or descending. There is more chance of an accident happening to the ascending train, as its rope is more strained; but the conditions of stopping are also more favourable in that direction, as will be seen just now.

The brakes contain two groups of distinct apparatus : 1st, one simply skidding the wheels; 2nd, the other acting equally by friction on the

rails; but this friction is due to a very rapidly increasing pressure, and independent of the weight, like the adhesion on a central rail.

1st. *Skidding of the wheels.* It is produced not by blocks acting on the tyres, but by crane-brakes the straps of which take on to discs attached to the wheels. Each of the four wheels has its own one (*figs.* 1 and 2). Counter weights P, P, P, P, put on levers l, l, 3 ft, 28 long, keyed on the shafts a, a, of the brakes, are kept lifted by the supports s, s, on which the prolongations of the levers l, rest. But if the draw-bar ceases to be drawn on, the traction spring with a clip t, t, in unbending, causes the shafts a, a, to turn; the supports s, s, being withdrawn, the counterweights fall, and the wheels are locked. This first brake would be not only incapable of destroying in a very short space of time the *vis viva* accumulated in the train; but it would be even insufficient, in certain states of the rails, only for balancing gravity, and to prevent simple acceleration.

2nd. *Emergency brake.* The complementary apparatus, or correctly speaking, the principal apparatus, is placed in the transversal plane of symmetry of the frame. To the shaft ω is suspended, by cranks μ, μ, and rods β, a shaft A on which are keyed two pulleys with conical throats π, π, which are exactly above the rails. Each pulley is contained between two jaws M, M, jointed in O; on the external face of each is applied a block E, forming a nut for the corresponding bearings of the shaft A, bearings screwed in contrary ways for the two jaws of the same pair; whence it follows that if the pulleys π turn in the suitable direction, the jaws come together. That fixed, in the normal state the whole system is up *in the air*, kept in that position by a cam γ (*fig.* 1) engaged in a notch in the slide δ, pressed by the spring ρ (*figs* 1 and 2); but as soon as the coupling bar unbends and recoils, brought up by the springs t, t, it draws back, by the rods and the lever x, y, z, the slide δ which lets go the cam γ; the apparatus falls causing the shaft ω to turn; the conical pulleys grip the rails, turn, and with them the shaft A.

If it is a question of a descending train, the direction of the rotation is such that the nuts E, and consequently the jaws M, M, of each pair come together, and grip the rail with very rapidly increasing power, which determines the immediate locking of the pulleys, then stoppage.

At the regulation speed of 6 ft, 56 a second, the locking takes place in one single turn of the pulley, and the stoppage at the end of a distance of 21 ft, 33, reckoned from the locking.

If the train is ascending, it still runs in virtue of its required velocity of 6 ft, 56 a second, nearly 4 ft, 25, from the instant the tractive effort ceases, and the action of the brakes on the wheels has commenced. During

this distance, the direction of the rotation of the shaft A is such that the nuts E of each pair separate; but they have come back to their normal position when the waggon has run back 4 ft, 25 and it has acquired at that moment a velocity all the less that the wheels have not ceased to be locked. This velocity is always below 6 ft, 56 and then, as remarked by MM. *Molinos* and *Pronnier* (*), the conditions of stopping on the ascent are more favourable than on the descent.

The cam γ can also be set free by hand by the conductor.

The fall of the brakes of the first waggon determines that of the brakes of the second one.

The slacking of the cable, when the train arrives on the horizontals near the end of its course, ought not to determine the fall of the brakes, the relifting of which requires a certain time, which would be lost. A local action must thus supply at these points, that of the cam γ, and prevent the rotation of the shaft ω. On a prolongation of that shaft, outside the frame, is keyed a lever L, carrying a roller g. A wooden rail placed at a suitable height on the edge of the platform, and a little before the beginning of the horizontal, receives this roller before the cam is let go, and keeps sthe shaft ω in the same position, until the stoppage of the train. These pieces fulfil, of course, the same function at the departure of the train.

I have seen pretty often ill-timed falls of the brakes take place through the negligence of the driver of the stationary engine, who ought to take care to avoid abrupt variations of velocity; they involve, for the traction spring t, oscillations which may have amplitude enough to cause the cam γ to be let free. In 1871, the wooden bar was lengthened 4 ft, 92 in order to prevent these accidents, more surely but not however in an absolute manner, for one has occurred since to an ascending train which was still 42 ft, 6 from the beginning of the bar, that is to say still on a gradient of one in 6. Such facts show a very negligent or inexperienced driver.

Beyond these little mishaps, which have become relatively frequent, but easy to prevent by a proper choice of enginemen, the system of brakes at the *Croix Rousse* presents all the guarantees that can be desired. Periodical trials of letting go the brakes are made in the presence of an officer of the Railway department, and always with success; as to the letting down in service, it has only taken place in the cases pointed out, that is to say unusually. No rope has ever broken; they are tested, which is quite proper, at

(*) Note on the brakes applied to the vehicles of the *Croix-Rousse* line. *Annales des mines*, 5th Series, vol. XX, 1861, page 621.

intervals the closer together, the longer they have worked and their wear more marked; and this obligation of tests more and more frequent, leads the company ordinarily to replace ropes, which would be still able to last some time.

Although the speed is very low, and the permanent way has no locomotives to carry, it is however and ought in effect to be very solidly constructed; if the rails have not, as have those of ordinary permanent ways, to withstand the weight of the motor and the tangential reactions of its wheels, they have, on occasion, to resist an effort otherwise very considerable, that necessary, on such an incline, to stop the train very rapidly, in the case of the rope breaking. The engineers have given the preference to a line with *Vignoles* rails, and longitudinals solidly tied together by cross pieces.

The mode of action of the jaw-brake which seizes the body of the rail, excluding fish plates, the consolidation of the joints was effected by covering plates bolted on, turning over the foot of the rail.

At the outset there were two distinct services: passengers, and goods; each line branched off at its two ends: one of the branches being for passengers, the other for goods (Pl. XXXIV, *fig.* 10); there were thus two ropes and two systems of supporting pulleys placed alternately on one side and the other of the axis of the joint line. But this complication was soon given up; there is no longer a special service for there cart-trucks: they are simply added, when occasion requires, to the passenger-carriage.

There is a plane analogous to the preceding one, on the Taff-Vale line, between *Aberdare* and *Merthyr* (Wales), serving also for passengers; the inclination is one in 12,5 only.

An inclined plane, a great portion in tunnel, is in construction at *Constantinople*, for connecting the quarters of *Pera* and *Galata* under conditions very similar to those of the *Croix-Rousse* plane. The inclination reaches one in 6,7, the height surmounted is 213 feet. The mode of working will be the same as at *Lyons:* stationary engine on the summit, rope with two ends, ascending and descending trains nearly balancing each other.

447. *Automotor plane at Ofen* (Hungary). — This plane was established in 1870, for connecting the lower portion of the town to *Königsburg*, which is 148 feet above it (Pl. LXXXIV, *figs.* 1 to 8). This height is made up by a plane 295 feet long, that is to say at an inclination of one in 2, or 30°. As at the *Croix-Rousse*, there are two lines, each of which serves alternately for the ascent and the descent; but the installation and the mode of action of the motor as well as of the special brake are altogether different to those at the *Croix-Rousse*. The motive apparatus is at the foot of the

inclined plane, which involves serious modifications in the system. The rope passes, at the summit, over an inclined return pulley P, and, below, its two ends, are wound in contrary directions on two cast-iron drums T, T' (*fig.* 3), 9 ft, 6 in diameter, which receive contrary rotations from two horizontal coupled engines M, M' by the pinion p, driving the bevel-wheels r, r'. The descending end winds on the moving drum, while the ascending end unwinds freely off the other.

In this arrangement, the two ends are constantly in equilibrium, but the length of the cable is doubled, as well as the resistances due to the supporting pulleys. The ordinary arrangement, with the motor at the summit and rope with two ends is more economical and more simple, and that of the *Ofen* plane could only have been justified by want of available space at the top.

The bodies of the waggons, which are not turned, are formed of three compartments of eight places, with their seats horizontal when the frame is inclined at 30°. These three compartments are staged so that they are at the same height above the staircase forming a platform, and consequently equally easy of access. These vehicles present two peculiarities: 1st, the suspension on four cylindrical blocks of india-rubber placed on the axle-boxes; 2nd, the application of a ring of friction rollers to the journals. This expedient is admissible at very low speeds (79) but the diminution thus gained of the effort of traction is very insignificant in this case, against that required by gravity.

Means of stopping. — Brake founded on the principle of the parachute in mines. — The drums T, T', are provided with powerful crane brakes. As to the safety-brake applied to the waggons, and which ought to act automatically in case of the rope breaking, its principle is borrowed from the parachutes made use of in mines, an application naturally indicated by the enormous inclination. Each of the two lines is inclosed between two retaining walls, the coping of which is formed of longitudinal sleepers l, 1 ft, 0 by 4 ins, 72 fastened into the masonry, and on a level with, on their upper face, the lower face of the longitudinals of the frame. These longitudinal sleepers represent those of the guided shafts, into which go the claws of the parachute.

The coupling bar b, b, is connected by rods t, t' to a wrought iron plate KK of trapezoidal shape, the convergent sides of which are furnished with teeth, geared into those of the discs d, d, fitted on to the carriers, q, q, which are continued to stops e, e. As soon as a sufficient effort, but one very inferior to that which attaches the cable to the waggon, either ascending or descending, is exerted on the hook c, the bar b goes forward

about 8 inches, compressing the spring *r*. It involves in this movement the rods *t*, *t'* and the plate K which butts against the stops *e*, *e* and turns thus, underneath the frame, the discs *d*, *d*, which no longer project over the longitudinals. At the same time that this movement is effected, the two counter-weights P P are raised and take the position P′P′, which they are always tending to quit in order to return to the former.

We see immediately what passes if the rope breaks: fall of the counter-weights P, P, recoil of the bar *b*, of the plate K, projection of the discs *d'*, *d'*, the teeth of which penetrate into the longitudinal sleepers *l*, *l*, and immediate stoppage of the waggon. To this effect concurs an analogous apparatus, placed behind the waggon. It is composed of two portions D, D, of excentric discs, with ratchet teeth turning round pivots *o*, *o*, and the prolongations of which, comprised between these two points, are toothed sectors *s*, *s* gearing together. Fastened to the coupling bar by the piece *m*, they retire when the bar is drawn forwards. As soon as, ceasing to be so, it recoils, they follow its movement, pass from the position D, to the projecting position D′, and thus press their asperities against the longitudinal timbers.

This brake is very efficient, very sure, but also very expensive, on account of the special constructions it requires.

For the mechanism arranged as indicated by *figs.* 6 and 7, 40 lbs suffice for each of the counter-weights P. The waggon weighs empty 2 tns, 80 and with its 24 passengers, 4 tns, 40.

In three experiments made by the passing committee, the cable was let go, on the ascent:

1. With the waggon	empty.	Stoppage after recoiling	....	1,38 feet
2. »	» loaded with 3 tons,	» »	....	1,71 »
3. »	» empty	» »	....	0,55 »

The rope, of iron wire is 1,0 inch in diameter, and weighs 4 lbs to the lineal yard. It underwent no permanent elongation with a tension of 12 tns, 5. The effort of traction of the waggon with its load of 24 passengers is only 2 tns, 15.

448. *Inclined planes of Santos.* — The most recent and also the most remarkable example of an engine and rope on a line of a certain importance is to be found on the line already cited (440) of *Santos* to *San Paulo* (Brazil). The escarpment of the *Serra do Mar* rises at this point by a slope of a quarter to one; it is passed by a series of four planes, having the same in-

clination, one in 9,75, and lengths respectively of 1,20, 0,63, 1,65, and 1,30 miles. At the summit of each of these, a piece of one in 77 has been managed for a length of 83 yards, sufficient for the train to start on, taking its rope.

Towards the foot of the upper plane, there is a deep gorge, crossed by a large viaduct in wrought iron, which thus presents the remarkable circumstance of being on an incline of more than one in 10. It is moreover on a curve of 656 yards radius. The arrangement of the lines, taken from that usual in England for industrial planes, is well known. There is a single line on the lower half, that is to say, to the beginning of the two-way crossing, with three rails, that is to say two lines having a joint rail on the upper half (Pl. LXXXIV, *fig.* 12).

The ascending train arrives at R, the pointsman opens the line N for it; the descending train arriving also at the same point by the line M, puts the points right for itself. When the trip is accomplished, the rope is found developed along A′MR, and for the following trip, it is the ascending train which takes the line M and the descending one the line N. The third rail avoids having points at S.

Each of the *relative* horizontals (*figs.* 11 and 13) has three lines; the ascending train always takes the middle line, and the descending train alternately the one and the other of the side lines.

The two ends of the rope pass over two return pulleys R, R (*fig.* 13) and enter into the engine-house; each plane is worked by two coupled horizontal engines of 150 horse-power each, with cylinders 2 ft, 16 in diameter, and 4 ft, 88 stroke, making 22 revolutions a minute. The cable, taken along by simple adhesion, winds up with the ends crossed, on the driving pulley 9 ft, 60 in diameter, with three grooves, and on a loose auxiliary pulley with two grooves. This method, which brings the stiffness of the rope into play by a multiplicity of windings, is not irreproachable, but on the other hand, taking it on only by adhesion is an excellent guarantee. Thus Mr. *Brunlees*, the engineer of the *San Paulo* railway, has recommended the substitution of a *Fowler's* pulley, for the two grooved pulleys (215). He thinks that in thus reducing the passive resistances, the cable would last longer than two years, the time it lasts at present, although it is only subjected to a tension of 4 tns, 5 at the most, while it is tested under a strain of 35 tons. It is in steel, and some engineers persist in considering iron preferable for this purpose.

At each end, the rope is provided with a solid coupling block in forged iron, and with a swivel to prevent torsion.

The normal load includes:

3 carriages or waggons, weighing............	24	30 tons.
1 brake waggon..........................	6	

The ascent of each of the planes occupies about a quarter of an hour. The actual traffic is 100.000 tons hauled; it would easily go to 500.000, only working ten hours out of the twenty four.

The safety brake (Pl. LXXXV, *figs.* 5 and 6), analogous to that of the *Croix-Rousse*, is composed of two clips *m*, *m*, with very long branches L, L gripping the rail, which is raised and thinned towards the top. It does not come into action automatically, as does that at the *Croix-Rousse*, by the sole fact of the breakage of the rope.

On the shaft *a* are keyed : 1st, the counter-weight lever P ; 2nd, the cranks *l*, *l* from which are suspended the rods *t*, *t*, carrying the jaws joined by the articulation β, and crossed by the shaft *o*, in the lengthened forks *k*, *k*, which yield to their vertical movements; at rest, the counter-weight P is lowered, and the jaws *m*, *m*, as well as the pedal π, raised.

To make the brake act, the conductor puts his foot on the pedal, and rapidly turns the fly-wheel V, which works the branches L, L, of the jaws, by means of screws with reverse threads, *v*, *v*, and nuts *e*, *e*, *e*, *e* taken by the forks *kk'*, *k'k*. The connection of the jaws, and consequently of the rails with the frame of the waggon, is established by solid guides in plate iron PP, a sort of guard plate between which slide the blocks carrying the jaws, suspended at α from the rods *t*, and taking hold of the branches L by the prolongation of the gudgeon β.

To take off the brake, he turns the fly-wheel the reverse way, leaving the pedal free. The counter-weight P lifts the apparatus up, and the vehicle can run over crossings.

Two cases of the rope breaking are given, one in 1869, when stoppage was immediately effected; the other in 1871, but this time the train was precipitated to the bottom of the plane. Details are wanting as to the severity of the accident. The brake does not seem to be sufficient as an emergency brake. It is also made use of when the rails are very wet, which occurs very often, in order that stoppage may be effected on the horizontals, exactly at the point fixed.

The solution applied by Mr. *Brunlees*, towards 1860, to the ascent of the *Serra do Mar*, has given rise to much controversy. A locomotive line developing with gradients of one in 40, and curves of small radius, would have involved expenditure the more inadmissible, the capital being limited,

and the mile of such a line coming to as much as a mile of the plane; on the other hand the schistous nature of the ground and the torrents of rain which dash down the escarpment, and the effects of which would be disastrous, if they were not met by enormous works, were powerful arguments in favour of the shortest line.

But many engineers have expressed the opinion that it would have been preferable to reduce the inclination to one in 16,6 or one in 14, with locomotive working along a central rail, either on *Fell's* system, or by rack and pinion. The partisans of the *Fell* system were evidently not informed exactly of the facts of the working of Mount-Cenis. The bold thesis has even been advanced, that it would have been advantageous, in the double respect of economy and power of traffic, to substitute the locomotive for the rope on the line as it is, with gradients of about one in 10, fixing the speed at 5 miles an hour. Mr. *Brunlees* himself does not seem far from admitting that if he had known of the central rail, perhaps he might have adopted it. What seems to us is that there is nothing to regret, and that the rope was the most prudent arrangement under such circumstances; and if the author of the project carried deserves to be criticised, perhaps it would be in not going further with the inclination by resolutely adopting a steeper gradient than one in 9,75. But it must be borne in mind that at a period when the jaw-brake, which appears to have originated on the inclined plane of one to one in the submarine mine of *Botallack* (*) in Cornwall, was not yet known, the question of means of stopping was predominant, and that an inclination of more than one in 10, was certainly of a nature to justify Mr *Brunlees's* prepossessions on the subject of the consequences of the breaking of the rope.

449. *Endless rope.* — An endless rope can be applied to automatic planes, but its length and its passive resistances would be doubled; it would require a special tension apparatus; lastly, a third rail would be necessary throughout; thus the endless rope is reserved for great lines, where the movement of the traffic in the two directions should be independent of each other. The utilisation of the descending weight is thus given up, and the engines must be established accordingly. The endless rope dispenses besides with changing the lines alternately, and is very well adapted to letting off the train from the rope without stopping.

The descent is done independently of the rope; it might be sometimes

(*) The inventor is Mr *John Rowe*, captain of the mine.

employed to moderate the speed, but it would be a very costly brake. Windings and unwindings, even under relatively slight strains, would hasten its depreciation, and ought not to be multiplied without necessity.

The descent is done then by brakes, and they should be the more numerous from the want of the locomotive with its counter-steam.

Inclined planes of Liége. — The system of planes at *Liége* offered a remarkable example, and one very well worked out, of the use of the endless rope (Pl. XCI, *fig.* 10).

The height surmounted is 361 feet; the inclination, one in 36 on the average, reaches one in 32 at some points. A single plane formed of one piece of straight would have been difficult and very costly on account of the ground: on the other hand, the length of a plane is evidently limited; if too long, the resistances inherent in the rope would be excessive, and the useful effect far too small. It was for this double motive that M. *Maus* divided the height into two of 180 ft, 5 each, and joined by a piece of level on a curve; the two straight lines are at an angle of 32°. By an ingenious arrangement, the motor of the lower plane was at its summit, and that of the upper plane at its base, so that all the boilers and engines were grouped together at one point. Beyond the evident advantage of the concentration, there was another not less important: each of the two engines could serve either plane, so that they could take each other's place in case of repairs. Either with the two engines, a train on each of the two planes could be worked simultaneously, or with one engine, one train successively on the two planes.

The endless rope was placed along the axes of the lines. It left them to run underground, on the level, at the summit where the line goes into curve (*fig.* 10); a return pulley α directed one of the lines of the rope into the engine-house; it passed two and a half times round the two drums M, N, the one of which (at will) was put into gear, and the other put out of gear; thence it passed on to the moveable pulley P, installed on a tension-carriage drawn by a weight hanging in a well, came back on itself, passed over a second return pulley B, and went below the earth to end on a large underground and inclined pulley δ.

450. *Condition of taking on the rope by its adhesion on the driving drum.* — The tension determined by the straining carriage and the total development of the arc wound on the driving drum, ought to have correlative values, such that the driving drum cannot turn without taking the rope with it. The crossing of the rope, if the rotation of the two drums

in a reverse direction should have no drawback, has the advantage of increasing the development of the arc acted on for the same number of turns. But the benefit would be especially great if the two drums could both drive. The same total friction would then be got with half the number of turns, and consequently with a proportionate reduction of the resistance due to the stiffness of the rope. We shall soon come to an example of this arrangement, but it could not be made to work in with the system adopted by M. *Maus*.

The friction on the total arc wound on ought to be greater than the resistance of the train, plus the resistance incidental to the rope itself. Let us rapidly analyse the conditions of this transmission.

A cord being supposed perfectly flexible (Pl. XCI, *fig.* 12) embracing an arc S on a fixed cylinder of radius r, it is easy to determine the force P capable of making the cord slip, solicited at the other end by a force Q.

The tension t, at the extremity of an arc s measured from the origin A, is equal to Q plus the sum of the frictions on the arc s, which gives $t = Q e^{\frac{fs}{r}}$, f being the coefficient of friction, and e the hyperbolic logarithm base.

For $s = S$, $t = P$; whence $P = Q e^{\frac{fs}{r}}$. The total friction is:

$$P - Q = Q\left(e^{\frac{fs}{r}} - 1\right).$$

We deduce immediately from this, the condition under which a cylinder movable round its axis (*fig.* 13), and to which is applied tangentially a resistance K, will turn in a contrary direction under the action of a force P applied to a cord embracing an arc S, and having at the origin A of that arc a tension Q.

We have : $P = Q e^{\frac{fs}{r}}$; the friction $P - Q = Q\left(e^{\frac{fs}{r}} - 1\right)$

ought to be at least equal to K. Putting the equation, we have for lowest values of Q and P :

$$Q = \frac{K}{e^{\frac{fs}{r}} - 1}, \qquad P = \frac{K e^{\frac{fs}{r}}}{e^{\frac{fs}{r}} - 1}.$$

In the present case, it is the drum which receives the movement from the motor, and ought to transmit it, by the intermedium of the friction, in the endless rope, to that end where the resistance of the train is applied; and this rope receives from the special strainer the tension θ, such that the resulting friction determines its being taken along by the cylinder.

2θ being the total effort of the strainer, and consequently θ that of each line of the rope at rest, T the tension of the line drawn on, and t that of the other running at a uniform speed, K the sum of the resistances of the train and those of every nature of the rope, we have:

$$T + t = 2\theta$$

$$T - t = K = t\left(e^{\frac{fS}{r}} - 1\right),$$

$$\text{whence } t = \frac{K}{e^{\frac{fS}{r}} - 1}, \qquad T = K + t = K\frac{e^{\frac{fS}{r}}}{e^{\frac{fS}{r}} - 1},$$

$$\theta = \frac{1}{2}(T + t) = \frac{K}{2}\frac{e^{\frac{fS}{r}}}{e^{\frac{fS}{r}} - 1}.$$

Such is the relation to establish, K being given, between θ, S and r, for the determination of the force with which the rope is taken along.

θ is constant for the same value of $\frac{S}{r}$, that is to say of the total angle wound on. There would thus be an advantage in employing small drums, which would be more economical, if K were constant. But this quantity includes the resistances of the rope, and they increase, with the equality of diameter wound on, when the radius of the drums decreases; and the increase of the resistance involves that of the diameter of the cable, which itself reacts on the resistances due to its weight, and more still on those due to its stiffness. So that it is very important to give the drum on the contrary a very large diameter.

The transmission of the efforts by the intermedium of the friction does not present in this case, as in that of the adhesion of the driving wheels of locomotives, the advantage of simplicity. It is on the contrary very complicated. But if it wants simplicity, it has other and great advantages. It offers an admirable guarantee against overstraining the rope, against shocks, seeing that it limits the maximum strain to which it can be subjected, and which cannot exceed that corresponding to slipping.

451. The trains descending alone, without being attached to the cable, the powerful means of stopping presented by the locomotive and tender on locomotive lines, were replaced at *Liége*, by special brakes (*Laignel's* type). On a gradient which now-a-days has nothing absolutely unusual in it for locomotives themselves, these means are perfectly sufficient, and they become even useless, when the locomotive takes the place of the stationary

engine, safety being perfectly guaranteed by ordinary brakes supplemented by counter-steam. For steeper inclinations one might be tempted to accept, in spite of its drawbacks, the connection of descending trains with the rope. But the possibility of its breaking, either on the ascent, or on the descent, being ever in view, it would always be necessary, definitively, that the train should possess in itself, and independently of the rope, means of controlling its velocity with certainty. The friction due to the weight of the train being altogether insufficient on such gradients, even with all the wheels locked (or better still, on the point of being so), an indispensable guarantee of safety must be otherwise sought for.

Endless ropes should be double the length of the inclined plane, without reckoning the supplements required by the connection with the engines, and the straining apparatus. The great amount of the tractive effort necessitates a large diameter for the rope, which reacts on the resistances and consequently on the diameter itself; it is especially in the stiffness, brought into play at all the bends, and which increases in a progression little known, but certainly rapid, with its diameter, that consists the great drawback of the rope with direct traction; while in winding only on drums of great diameter, the stiffness alone absorbs a considerable amount of work.

Let us add that the system of direct traction, particularly in the case of passenger lines with endless rope, excludes curves of small radius. On the one hand, numerous bends over the pulleys, would greatly add to the resistances, and the useful effect of the motor, which has at the same time to overcome the resistances due to all the curves, would be much reduced; on the other hand, if the rope slipped off the pulleys, its abrupt straightening might be attended with serious consequences.

This condition, generally accepted, of the straight line, is very hard on the construction of the line. It necessarily results, in the same circumstances, in a higher rate of inclination than if the question were of a locomotive line, which certainly allows relatively great liberty of inflexion. Thus a legitimate comparison between the two systems of traction : locomotive, and rope with stationary engine, can not be established, by supposing them applied to the same trace; under the same conditions, the first is far from requiring such steep inclinations as the second.

Power of the engines. P being the weight of the train, r its resistance on a level, $\frac{1}{i}$ the rate of inclination, R the sum of the resistances of the cable,

V the velocity, we have for available work on the driving shaft of the engines:

$$T = \left\{ P\left(\frac{1}{i} + r\right) + R \right\} V.$$

At *Liége*, they took:

$P = 60{,}00$ tons | $r = 0{,}005$ | $V = 18{,}17$ feet (12,42 miles an hour).

besides $\frac{1}{i} = 0{,}0277$.

As to R, the estimation of the divers resistances by known rules gave $R = 0$ tn, 69. We have thus:

$$\left.\begin{array}{ll} PrV = 12{,}065 & \text{foot pounds.} \\ \frac{P}{i}V = 72{,}531 & \text{»} \\ R\,V = 27{,}775 & \text{»} \end{array}\right\} 112{,}171 \text{ foot pounds} = 204 \text{ horse power.}$$

The real power was: 248 horse.

The connection of the train with the rope was easy to establish, and a point of importance, easier to suppress: It was effected by the intermedium of vehicles which acted at the same time as sledge-brakes, and which acted, of course, on the descent as well as on the ascent, but in the first case, without being attached to the rope.

Figs. 16 and 17, Pl. XCI, shew clearly the mechanism of the coupling. By means of a jointed lever, with segment and pawl, working on the centre O, the rope was locked between the two jaus m, m': the pawl d, maintaining the pressure. To let go, the brakesman had only to tighten a little more at first, so as to let out the pawl.

We shall dwell no longer on an application which has now disappeared (258). In 1866, the locomotive had for years been taking the place of the rope for passenger-trains; and if M. *Maus's* arrangements were still working the goods traffic, it was easy to foresee that would not last long; it is probable even that the advent of the locomotive would have been less delayed, if a natural scruple had not hesitated at the destruction of a work of incontestable merit.

Prussia was not so particular. Long since, locomotives replaced the stationary engines of *Aix-la-Chapelle;* the incline was only a little less steep: one in 38.

The installations at *Liége* having long before become, altogether insufficient for the incessant progress of the traffic, the Belgian direction found itself in this alternative: either to put these installations into keeping with the requirements of the traffic, which would have involved con-

siderable expense; or to realise the value of all the appurtenances connected with the traction by the stationary engines, the ground especially, and have recourse to powerful locomotives relatively light; their success being all the less doubtful, as if the incline is heavy, the trace on plan is as favourable as possible, being composed of two straight lines.

The introduction of tank-engines with eight wheels coupled mentioned higher up (258) has proved in all respects a step of progress; the working of the incline having become more economical and more simple.

452. The height to be overcome being given, and, if it be too high, divided, it may be asked what is the most suitable inclination for planes with stationary engines.

Theoretically, there is no maximum, and the lift can be gone up to 90°. It is so in mines where the vertical shafts reach depths of from 2.300 to 2.600 feet, and then will soon be exceeded. The deeper the shafts go, the more important it becomes for them to bring up more, their enormous cost not permitting them to be multiplied, so that each of them should serve a large extent of working. The acceleration of the speed must therefore go hand in hand with the increase of the loads of the buckets: the speed being already that of goods-trains on railways, that is to say, from 26 to 30 feet a second.

There are doubtless no grounds for making these shafts, these vertical tunnels, part of the trace of railways on the surface; but the shape of the ground may conduce to extremely inclined gradients, in the open.

There are indeed, it is true, on some industrial railways, examples of *dry locks*, getting over heights of only a few yards by a vertical movement of lifts.

The effective work to be produced in raising a train to the summit of an inclined plane, is composed of two parts, which correspond, the one to lifting the weight, the other to the resistances proper. The first is independent of rate of inclination with which a given height is got over, the second is less, the greater this inclination is; in this respect, the lift would have the advantage seeing that this second work is nothing. It would also have the advantage in the length of the rope, reduced then to a minimum; but the tractive effort, and consequently the diameter of the cable would on the contrary be maxima, and even altogether excessive, unless by pushing the division of the trains to a point absolutely incompatible with an active traffic.

453. *Influence of the weight of the cable* — The weight of the rope is

one of the principal causes which limit the inclination to be given to a plane with direct traction, surmounting a given height. p being the weight of the unit of length of the rope, l the length of the plane rising up the height h, with an inclination the sine of which is $\frac{h}{l}$, the parallel component of the weight of the rope, is $p.l \times \frac{h}{l} = ph$. It would thus be independent of the inclination if p were constant; but the effort of traction of the train itself increasing proportionally to $\frac{h}{l}$, p also increases with that inclination, and more rapidly.

It is of consequence to remark that this influence of the weight of the rope (independently of that which it exerts on the resistance due to its supports), is in no way peculiar to the rope with one or two ends; it affects just as much the endless one. The two lines are in equilibrium, but the rope has none the less to support, at the summit of the plane, the effort necessary to lift a weight equal to the component parallel to the plane, of the whole of the ascending line.

With the rope and direct traction, very severe inclinations would have the effect of reducing the useful load in such proportions that the division of the trains would become excessive, the loss of time at the two ends of the plane multiplied, and the capacity of the plane for traffic reduced beyond measure.

454. *Secondary applications of the stationary engine to direct traction.* — The stationary engine and rope has received in some particular cases, secondary applications. Thus on the atmospheric line of *St. Germain*, a windlass worked by air served to start the train on the level of the *St. Germain* station, a level which is followed by the down gradient of one in 28,6 (Pl. XCII, *fig.* 5).

It is also similarly that the stationary engine has been employed in the new tunnel under the Thames, constructed for the purpose of freeing London Bridge of some of its overburthen. This passage (Tower Subway) 546 yards below London Bridge, proposed by the late *Peter W. Barlow*, has been carried out by his son, by a process as expeditious as economical. It will be sufficient to state here that the tunnel pierced through the plastic clay is circular in section, and formed of cast-iron rings bolted together. It is 7 feet in diameter internally, and 440 yards long from shaft to shaft; one shaft being 63 feet, and the other 56 feet deep.

The longitudinal section presents at each end a horizontal portion 100 feet long, then an incline down of one in 40: these two inclines being joined in the middle by a curve. The depth of the shafts being given, this section insured a sufficient thickness of ground above the tube: 22 feet at the lowest point of the bed. It was besides in keeping with the mode of locomotion adopted at first: a stationary engine giving the carriage sufficient impulse for it to run up the other side.

There was at the bottom of each shaft, a 4 horse engine working the lift: that on the Surrey side gave velocity to the omnibus, by means of an endless rope, regulated by the guard with a pedal-brake, after having let go the carriage from the rope.

The total duration of the trip was 3 minutes; the carriage had longitudinal seats, was entirely of iron, and weighed 2 tons.

This speculation in mechanical transport having had little success, was given up; the mechanical appliances of the shafts replaced by flights of stairs, and the *Tower Subway* has become a simple passage for pedestrians, as was for so many years the famous Thames tunnel, and even then by scarcely more than sight-seers. But at last the work of the elder *Brunel* has become utilised. It now forms part of the East London line, which connects, as an extension of the South London, the *Brighton* line with the new Liverpool-street terminus of the Great Eastern; passing under the Thames, and under the London Docks. Locomotives are now running at very frequent intervals through the tunnel, and some mistrust was not wanting as to the effect of the vibrations on the impermeability of the brickwork; but these fears have not been realised. The running of the engines has not produced the slightest leak: the tunnel remaining perfectly water-tight.

§ II. — System of M. Agudio.

455. We now come to a composite system, which by its ingenious and logical principle, by the success of the experiment on a great scale to which it has been submitted in Italy, has excited legitimate interest.

On lines with steep gradients, the locomotive has the disadvantage, inseparable from its nature, of an extremely reduced useful effect. A great portion of its power is employed in producing useless work that is to say drawing itself. Reduced by a lowered speed which requires, from a certain limit, special arrangements, such as the central rail (425), or a line with a rack (432), this disadvantage exists always in a high degree;

and it tells heavily on the working, while the construction itself suffers by the necessity of developing the extent of the line, so as to bring the gradients within tolerable limits.

We are thus brought back to the stationary engine; but that has against it the cost and the inseparable resistances of the intermedium which transmits the work to the train; and the most simple mode, that is to say the rope acting by direct traction, is subject, as we have just seen, to very serious imperfections.

The main feature of M. *Agudio's* conception is a considerable reduction in the section of the rope, and consequently in its weight, and of the amount of its resistances proper. This reduction is obtained by two principles, united in the great experiment at *Dusino*, but which may be separated. These are: 1. the utilisation for the traction of the descending line of rope, which works like the ascending one; 2. the amplification, in a perfectly arbitrary ratio, of the velocity of translation of the rope, four times, five times if desired, that of the train: whence a reduction, in the inverse ratio, of the effort of traction to be transmitted by the rope, and consequently in the section thereof.

The first of these principles excludes, quite as much as the second, direct traction, seeing that the contrary efforts of the two lines of rope neutralise each other. Each of them, then, acts by a couple, determining the rotation of one or more *driving axles*; and the part of the rope is to convey to these axles the work of a fixed motor, the same as in the locomotive the pistons transmit to one or more axles, the work developed in a boiler solidly attached to the vehicle.

The *Agudio* system is thus really a combination of the ordinary rope system, and the locomotive system. This is the more exact as the action of the descending line of rope and the transformation of the velocities require special machinery, which represents what remains of the locomotive. This special apparatus, the *locomotor*, is a dead weight, but a dead weight almost independent of the work it transmits, and thence very small relatively to that of the very powerful locomotives, which even a light train requires on heavy gradients. It has thus been successfully managed to escape in a great measure from the drawbacks of direct rope traction, and from those of the locomotive.

As to curves, the bending of the cable over the pulleys must of course be put up with; but their resistance is greatly diminished by the very fact of the reduction of the diameter of the rope: as it also is by the arrangement of the pulleys (464).

The adhesion of the locomotor gives only a small item if it be not completely left on one side, as in the first and the third form given to the system.

456. *Dusino installations.* — Let us begin by pointing out the first form, under which it was applied at *Dusino* (Pl. XCI, *fig.* 7).

This system is essentially for a single line; the ascent and the descent are effected on the same rails, the locomotor being necessarily devoted, on account of its connections with the rope, to a single line, on which it runs forwards and backwards. It fulfils a main function on the descent, if the incline is heavy (as it ought to be); the most powerful means of stopping being concentrated in it, it guarantees the safety of the train.

The rope, an endless one, has its two lengths placed symmetrically on each side of the axis of the line; the symmetry exists also for the impulsions which definitively determine the progress of the train, thanks to the arrangement which constitutes one of the salient features of the system, that is to say, the division of the work between the ascending line of rope, and the portion of the descending one comprised between the train and the bottom of the plane.

To realise this division, each of the lines of rope must be acted on by a distinct motor. Thus while at *Liége* the engines working the two planes distinct and independent, were united together into a group placed on the piece of horizontal by which the planes were joined (*fig.* 10); at *Dusino* on the contrary, the motive power for the one single plane was divided in two of the same force, placed on the side, one at the summit, the other at the foot.

Let us remark, before going any farther, that the efforts equal and contrary of the two lines of rope, give rise to a couple parallel to the line, which tends to make the locomotor turn round an axis normal to this plan; but this is an entirely theoretical drawback, on account of the very reduced tension of the cable, the little distance the lines are apart, and the great length of wheel base of the locomotor.

Some engineers had expressed an opinion that the impossibility of maintaining in equality the running of the two motors would give rise to continual slipping of the rope on the drums; experience has most clearly shown this fear to be unfounded. The equality of the running of the two engines takes place itself, and without being looked after; they regulate each other by the intermedium of the rope; no inequality in the running

takes place, precisely because it could not occur without the resistance of the rope to slipping being overcome.

Let us examine successively the mode of action of each of the lines of rope.

1. *Ascending line of rope.* — The principle amounts to winding the cable on a vertical pulley, installed on the locomotor, and transmitting, by a pinion keyed on axle, the rotation to a towing wheel (*figs.* 7 and 14) the teeth of which would gear at the same time into those of a central rail. As soon as the rope is running, the pulley drawn on by the friction developed by a straining-apparatus similar to that at *Liége*, turns on its axle and the train runs, the towing wheel being unable to slip.

It needs not be said that the pulley of the locomotor has, like the drums of the fixed engines, which take the rope also by friction, an auxiliary one installed on the locomotor, loose on its axle, and which returns the rope.

R being (*fig.* 14) the radius of the pulley, ρ that of its pinion, and V the velocity of the train, the velocity at the circumference of the pulley is $V\frac{R}{\rho}$, and the absolute velocity of the cable is $V\frac{R}{\rho}+V$.

If this velocity be taken for example at 2,25 times that of the train, we have

$$V\left(\frac{R}{\rho}+1\right)=2{,}25\,V, \qquad \text{whence} \qquad R=1{,}25\rho.$$

2. *Descending line of rope.* — This line winds, like the other, on two pulleys of the locomotor, one of which is an auxiliary; it drives in the same way the towing wheel by a pinion (*fig.* 15), but the latter acts on the inside of that wheel, in order to impart to it a rotation in the same direction as the exterior pinion, moved by the ascending line of rope.

The radius ρ_1 of the interior pinion is besides determined; it derives from the condition of the equality of the absolute velocities of the two lines of the rope. The velocity of the circumference of the pulley on which the descending line of rope winds being $\frac{VR}{\rho_1}$, the absolute velocity of this line is $V\left(\frac{R}{\rho_1}-1\right)$, whence for the condition of equality of the absolute velocities of the two lengths of rope:

$$V\left(\frac{R}{\rho}+1\right)=V\left(\frac{R}{\rho_1}-1\right),$$

and because of $\frac{R}{\rho}=1{,}25$,

$$\rho_1=\frac{R}{3{,}25}.$$

Hitherto the machinery proper, that is to say independent of the simple supports, comprises then, for each line of rope, two pulleys of which one is auxiliary, and a pinion; this pinion is exterior to the towing wheel, for the ascending line, and interior for the descending line.

Adhesion cable. The towing wheel, which we have supposed furnished with teeth and working along a rack, takes its point of support in reality from a cable rolled round it, and attached to a fixed point on the summit of the plane; at its lower end this cable is solicited, as the moving rope, by a tension carriage which does not allow the towing wheel or rather *adhesion drum* (name given to it by M. *Agudio*) to slip on the fixed or adhesion cable, so long as the resistance referred to its circumference does not exceed the limit fixed according to the conditions of the service.

It needs scarcely be said that the adhesion drum has, like the other pulleys either fixed or moveable, and for the same motive, its auxiliary drum, and that the straining weight, and the number of spires, that is to say the total arc S, are determined correlatively (448).

The transmission of the effort of the motor rope, moveable, to the adhesion cable, requires altogether six pulleys or drums and two pinions (*fig.* 7). It is important for these drums to have large diameters, in order to reduce the work absorbed by the stiffness of the rope and the cable, and more still to save them. The six large pulleys and the two pinions are installed on a large frame l, l carried by two bogie-trucks, so that this vehicle easily runs through curves of small radius.

What precedes being well understood, figures 3 and 4, which represent the real locomotor, and on which the same things are designed by the same letters as on figures, 7, 14 and 15, require but few fresh explanations.

The transmission by friction, a valuable guarantee of the preservation of the ropes which can never be subjected to an excessive strain, whatever may happen, has been also applied to the transmission to the adhesion-cable, of the effort of the ascending line of rope; the pinion F is a friction wheel placed between the two pulleys K, L, (*fig.* 3) keyed on the axles of the drum b, and its auxiliary b', and powerfully held together by the lines of the adhesion cable, which tend to bring them together. It involves thus the two drums at once in its rotation; so that the auxiliary becomes a motor like the other. This arrangement has yet another advantage: that is, to relieve the axles and bearings of these two drums from a very considerable effort.

As to the pinion driven by the descending line of rope, placed as we hav

seen (*fig.* 15), inside the adhesion drum, the transmission by the friction due to a heavy pressure was much less easy to realise: it would not besides have had the same advantages. There is in this case, gearing, but it is the only one.

The locomotor can be placed in front of, or behind the trains, but the best way is evidently to place it, as the Rigi engine is placed, behind on the ascent, and in front on the descent.

On the platform is the conductor, who is as much master, as the driver is of his locomotive, if not more so.

In effect, the pulleys driven by each of the lines of the motor cable can, by means of a clutch, be rendered, at will, solidly connected with the axle of their pinion, or independent thereof.

Faithful to the principle of the transmission by friction, the inventor has rejected chuck clutches, inadmissible in effect in this case, on account of the shocks at starting, and adopted the well known one of M. *Kœchlin*. The two levers can be worked either simultaneously, or separately; the conductor can, at any moment, isolate the ascending train from the motor, let it run backwards more or less, while the rope goes on its way, and take up again the connection when he thinks proper. This faculty would not doubtless be of frequent use; but it is unquestionably very remarkable that the train, hauled by motors perhaps some miles off, should be in the hands of the man on the locomotor, as much as if it were drawn by a locomotive; this is a property which ought to strike its exclusive partisans. They urge, and justly, the docility, the pliancy of this admirable machine; but we see that in giving it up on gradients where it is as it were paralysed, advantages which hitherto it possessed only are not given up on that account.

The division of the motor between the two extremities of the inclined plane involves a consequence, almost indeed self evident. In the ordinary system by direct traction, the rope passes, at one end of the plane only, over a pulley with a straining carriage, and at the other over a fixed pulley (*fig.* 8). Here the driving rope is solicited at one end of the plane as at the other, by a strainer, an indispensable appurtenance of a motor which acts separately on each of the lines of rope (*fig.* 9).

The rope motor forming thus a system independent of any fixed point, and susceptible consequently of some displacements in mass, in case of slipping on the fixed pulleys, stops or buffers had been arranged to limit towards the inside the oscillation of each of the straining carriages. But experience has shown that such slipping was not produced in an appreciable manner.

The principal consequences of the arrangements just described, present themselves to notice : the main drawback of the ordinary system is the considerable diameter (2 inches at *Liége*) which the cable requires; costly of itself, it introduces by its weight and its stiffness passive resistances which become excessive beyond a limit, not very high, of length and inclination.

In the *Agudio* system, the division of the work between the two lengths of rope, reduces to one half, every thing else equal, the tension and consequently the size and weight of the rope. To the increase of its velocity of translation corresponds a new reduction of its tension which is thus brought down, for the numerical elements indicated higher up, to $\frac{1}{2 \times 2,25} = \frac{1}{4,50}$.

It is true that if the dimension of the motor rope is reduced in such a ratio, if the effort which measures its passive resistances, its stiffness especially, is diminished in a considerable proportion, there are in addition the cost and the resistances proper of the adhesion cable, but of which only the stiffness comes into play, because it is fixed. On the other hand, if the motor rope is much lighter, and much less strained than in the direct traction system, the distance it runs is in return, greater in the reverse ratio, but far from compensating as to the work of the resistances. The gain due to the first reduction in section is fully got on a straight line, not quite on a curve. If, in effect, the diminution fully takes place for the resistances due to the supporting pulleys, it is not the same for the resistances due to the directing pulleys, the mean number of these, which are subjected simultaneously to the motor tension being twice as great for the new system as for the old. In the latter (*fig.* 9) the total length of the rope subjected to this tension, equal at starting to the length L of the plane, diminishes up down to 0, while in the other, that length is constantly equal to L. (We may remark in passing, that if the motor is at the bottom of the plane as was the case at *Liége*, with respect to the upper plane, the length of rope subjected to motor tension is 2 L at starting, and L at the arrival). Altogether the curves within the limits with which they can be admitted, only slightly diminish the gain due, as regards the resistances, to the distribution of the motor tension between the two lines of rope.

But the reduction of section which results from the increase in the speed of the rope has not, by a long way, so favourable an influence on the work of the passive resistances; the ones, that is to say the friction on the pulleys on their axles, being proportional to the weight of the cable, and consequently inversely proportional to its speed, there is compensation between the two factors of the work of their resistances.

There remains the stiffness brought into play on the drums, and in curves on the directing pulleys. If, as is often admitted, this resistance, everything else equal, is proportional to the square of the diameter of the cable, and consequently to the weight per unit of length, there is, in that also, compensation between the diminution of section, and the increase in the distance run. But the laws of these resistances are very imperfectly known, and doubt exists on the point. It ought to be admitted, every thing taken into account, that the reduction of section corresponding to the acceleration of the rope has no direct influence of consequence on the reduction of the work of the passive resistances; but the great advantage of this acceleration, is to reduce by half, two thirds etc., the weight and consequently the cost of the cable.

457. *Curves*. — For inclined planes with direct traction, established on passenger lines, a straight line has always been considered as a necessity which could hardly be dispensed with. The taking side of the atmospheric system (471) was to give much more liberty with, both in plan and section, not only than the inclined plane, but than the locomotive itself; on the other hand, and however the direct view of the train may be made up by an index progressing proportionally thereto, and placed under the driver's eyes, it was thought well that he should, as much as possible, see the train himself from his post.

It was the influence of the curves and of the length on the resistance which led M. *Maus*, at the same time that he rejected the one, to limit the other. In getting over by two distinct inclined planes the 361 feet, difference of level between the Meuse and the plateau of *Ans*, he at the same time reduced by one half the resistances incidental to the rope, which the motor had to overcome at once (more than half even, the diameter of the rope evidently requiring to be increased with its length by the very fact of these resistances), and simplified the establishment of the platform. The two straight lines making a considerable angle (58°), did not require to leave the natural surface of the ground so much, and thus dispensed with a good deal of the work involved by one straight line.

This almost absolute necessity of the straight line, and of restricted length, the limit of which depends moreover on the inclination, by reason of the influence thereof on the diameter of the rope, is so weighty an objection that the *Agudio* system, in spite of the advantages enumerated above, would be of but limited importance, if it also, were subjected to that necessity. But

the inventor has been able to free it from that necessity, within pretty wide limits.

He first took from *Atwood's* machine, for the axles of his supporting and directing pulleys, a well known arrangement, and an experience of two years at *Dusino* had sanctioned that mechanism, which might at first be looked on as rather delicate and subject to too many chances of derangement. We shall not describe those first apparatuses, the inventor having found that they could be simplified, at the same time retaining great mobility. (Pl. LXXXVIII, *figs*. 3 to 8).

The adhesion cable, being fixed, does not require supporting pulleys; on curves it is directed by simple vertical posts, fixed on the cross sleeper by an iron trenail and steadied by a strut (Pl. XCI, *fig*. 11).

The rims of the adhesion drums passing lower than the tops of the posts, the latter must allow the former, necessarily placed on the axis of the line of rails, to pass. The posts are thus placed on curves, a little out of the axis of the line, towards the inner rail; when the drums come near a post they draw away the cable therefrom, bringing it back to the axis of the line.

As to the motor rope, on a straight line it is supported, and on curves, supported and directed by pulleys with horizontal axles in the first case, and rollers with a vertical axis, in the second case. This second apparatus is much more satisfactory and more sure than the inclined pulley first employed at *Dusino*.

The reaction of this pulley ought to balance the horizontal resultant R (*fig*. 18), of the tensions of the two lines of the rope α, β, and the weight P, of the length of rope lying between two consecutive pulleys. The radius OA ought thus to be directed along the resultant of the two forces R and P, a condition which could not be fulfilled exactly, the tension at each point being T, or t, according to whether the train is within or beyond that point. It was thus necessary to give the directing pulleys an inclination calculated from the mean value of R; which, however, had no disadvantage; but the object is attained much more surely by the rollers with vertical axles described farther on (464).

The improvements applied to organs which play so great a part, especially on the curves, have a very marked effect in the elevation of the useful effect obtained; they are not, without doubt, inherent to the system, although by the very fact of its much reduced tension and weight, the *Agudio* rope adapts itself better than the ordinary rope to a more delicate and more complicated construction of the directing pulleys. Even, moreover, if nothing hinders

the application of these improved pulleys to ordinary inclined planes, the new system would none the less maintain the advantages peculiar to it, and which insure so great a superiority over the old.

458. Advantage was taken, for the installation of the experiment at *Dusino*, of a piece of line on the *Turin* and *Genoa* near *Villanova*, 1,40 miles long, which was abandoned through a deviation, on account of the bad nature of the ground; the inclination was moderate, it did not exceed one in 37; a great portion of the length was on a curve of 382 yards radius; on a trial line constructed for the purpose it would have been better to go beyond; but from the straight line, looked on until then as almost a *sine qua non* with respect to rope traction, to curves of 382 yards radius, was enough to satisfy the most exacting.

Although the *Dusino* experiment was made under conditions not very favourable: bad ground, indifferent permanent way, temporary establishment of the motors, insufficient study of some of the details of the mechanism, etc., etc., its success was complete. Every part worked with remarkable smoothness and regularity; and where ever the pulleys were well held down to the cross sleepers, the rope running at a velocity which reached 25 miles an hour, seemed immovable, so exempt was it from flapping.

Among the trials made under my eyes, and at my request, I shall give this. It may so happen that one of the motors becomes disabled from some cause. The train is not brought to a stand-still on that account, seeing that it can be hauled at a reduced speed, by one single motor and one line of the rope, without overstraining the rope. The disconnection of one of the motors evidently realises the above hypothesis. The tension of the line of rope, then become the only motor one, being higher than that for which the strainers were established, slipping of the rope took place on the grooves of the drum; and this slipping was rendered visible by a disengagement of vapor due to the distillation of the tar in which the hemp had been soaked lining the grooves of the drum. This perceptible sign, which shows up all slipping of the cable, is in itself a useful thing, because it calls attention to a fact, which should not occur in normal working.

It will be remarked that in this trial, the system of the rope with its two strainers not being, as under the ordinary conditions, drawn in one direction by one of the motors, and in the other direction by the other, had a tendency to displace in the direction of the single traction. The strainer should thus either go up home against its stop, or as was done, its carriage fixed to the rails of the line.

459. *Useful effect.* — 1. *Useful effect of the system.* The motors installed, the one at the top and the other at the bottom of the plane, were two of the fourwheeled locomotives (417) set apart for working the section from *Pontedecimo* to *Busalla;* a very favourable circumstance if it had been taken full advantage of, seeing that the gradient of one in 37 being very practicable for locomotives, nothing would have been easier than to compare their useful effects, according as they hauled the train by the intermedium of the rope, or directly.

Train drawn, not including the locomotor, 120 tons, at 10 miles an hour $= 14$ ft, 7 a second.

Gravity : $120{,}00 \times 0{,}27$	3,240 tons
Resistance : 13 lbs, 22 a ton $(\frac{6}{1000})$: $120{,}00 \times 0{,}006$	0,720 »
	3,960 »

13 lbs, 22 for the resistance may seem excessive at this low speed, but the curves of 380 yards must be considered.

As to the resistances relating to the two ropes, to the pullies, and the machinery of the locomotor, as exact an estimat as known experiments permit, puts their value at.... 3,032 »

Total resistance.. 6,992 »

There is thus : useful work : $3{,}96 \text{ tons} \times 14{,}7 = 18{,}11$ foot tons.

Work available on the shafts of the two locomotives : $6{,}992 \times 14{,}7$ 102,78 foot tons. Whence the useful effect : $\frac{58{,}11}{102{,}78} = 56{,}7$ per cent.

If it is borne in mind that it was a trial stock, offering defects from which a permanent establishment would be exempt, this return would appear satisfactory, and augur well for what would be attained under circumstances where economy would be less considered and more attention paid to mechanical perfection.

It must not be forgotten, at the same time, that there is an element the influence of which on the useful effect is very great, the length; that at *Dusino*, this was small (1,40 miles), and therefore care must be taken not to generalise on the above figure. We shall return to this point.

2. *Useful effect of the same engines coupled directly to the train.* Coupled directly to the train, the two same engines hauled 135 tons at 5,29 miles an hour.

At this speed the total weight, that is to say the locomotor weighing 20 tons included, drawn by the engines acting as stationary ones, would be, according to the preceding experiment, where this weight amounted to $120 + 20 = 140$ tons, nearly $\frac{140 \times 16}{8{,}4} = 266$ tons, or 246 tons of useful load,

instead of 135 tons, which would bring out in favour of the system a superiority of 82 per cent.

In an experiment made by the representatives of an English company, the weight hauled by the engines fixed was 142 tons or 162 locomotor included, at a speed of 7,15 miles an hour. At a speed of 5,20 miles an hour, the weight would be according to that experiment, very nearly

$$\frac{162 \times 11,5}{8,4} = 222 \text{ tons, or } 202 \text{ tons useful load,}$$

which would reduce the advantage to 50 per cent, still a very considerable figure. The experiment with the engines running was made in "exceptionally fine weather", it is stated. It must certainly have been so, and even under that condition, it is difficult to admit that locomotives could, at so low a speed as 5,20 miles an hour, really develop all their power without slipping. It appears in fact, that slipping occurred several times, and perhaps the engines could not, on that account, produce as much work under these conditions as when they were acting as stationary engines.

Besides, the comparison of the net weights hauled is not sufficient; that is only one side of the question. The cost and the maintenance of the ropes, the pulleys, the way, the locomotor, burthen the stationary engine system. The other has, per contra, to its debit: 1. the wear of the engine tyres; 2. the more expensive establishment of the permanent way, which must be more solidly constituted when to be run over by heavy locomotives with coupled wheels, than when it has only the carrying stock to bear; and in this respect the locomotor does not aggravate the position, as it is only a waggon itself, heavy it is true, but the weight of which is spread over a number of wheels, and only carrying wheels; 3. the locomotive, which burthens heavily both the cost and maintenance of the permanent way, and the more so, as for a given traffic the running of the engines is more active and consequently more destructive, the heavier are the inclines.

As to the action of the breaks, especially destructive with the locomotive for the descending line (385), it affects less directly the unique line of the *Agudio* system; the brake of the adhesion drum, bringing the effort on the fixed cable, saves the line. But experience only can determine up to what point it is advantageous to save the line, at the expense of the big cable.

460. *Means of stopping.* — We shall only here look into those which are special to the system.

It is unnecessary to state that the locomotor is provided with ordinary brakes *s, s;* but the weight of that vehicle ought to be limited to the strictly

necessary; as it constitutes comparatively to the ordinary rope system, an increase of dead weight, the more severe, the steeper the gradient. The locomotor must in no way be looked on as those brake-waggons, heavy in themselves and heavily ballasted, with which the trains on the *Liège* planes were loaded. The locking of even the whole of the wheels of the train would be besides altogether powerless, on very steep gradients, to which the mode of traction in question should particularly apply, and the inclination of which would often have to exceed, and by far, that of the *Croix-Rousse* plane (446).

The possibility of the ropes breaking must be quite admitted, and a means arrived at of guaranteeing the safety of the train without them; for gradients on which ordinary brakes would be insufficient, the application of a special brake, such as that of the *Croix-Rousse*, is indispensable. But before having recourse to that last plank of safety, the *Agudio* system possesses means of slackening and of stopping which are peculiar to it.

We may at first remark that the locomotor being placed behind on the ascent, and provided with a powerful brake, the breakages of couplings and their consequences are no longer to be dreaded.

As to the two cables, if rupture is possible for both, it is far from being so in the same degree. It is easy in effect, to render this accident very improbable for the adhesion cable, because there need be no hesitation in giving it a considerable excess of strength; but it is an other thing as regards the motor rope.

It is of importance to limit its dimensions, on the one hand, because of the price, this one being more than double as long as the adhesion cable; and on the other hand, and above all, because of the rapid progression which the resistances of this long moving rope follow (especially on curves), when its diameter increases.

The adhesion cable is fixed, and, on that account, brings no other resistance into play than its stiffness. By forcing its section a little then, it can be made the more reliable, the more so as the arrangements adopted for the transmission of the forces, put it, as we have seen, beyond the reach of accidental and considerable increases of tension. It is sufficient to give it such a diameter that under the effort corresponding to the limit, that is to say slipping, it still is only working at a moderate strain.

The chances of the breaking of the driving rope cannot be considered as so remote, by reason of its mode of action which fatigues it more, and of the less excess of resistance required to be given to it, so as not to render its weight, its price, and its resistances undue.

That being so, if such breakage takes place, the conductor has under his hand one of the most efficient means of preventing any running backwards on the ascent and keeping the train in check on the descent as long as the adhesion cable holds on. It is a brake B, B (*figs*. 3 and 4) acting, like those of cranes, on the rim of the pulley L, solid with the adhesion drum *b*, and which allows it to be locked at need. The train cannot in that case run backwards, if the accident happens on the ascent, nor continue its movement, if it be on the descent, without slipping taking place between the drums and the adhesion cable: an enormous resistance, to which would beadded if required, that of the ordinary brakes *s*, *s*, of the locomotor, and of the waggons.

Beyond these extreme cases, which must be provided for, but which the greatest care must especially be taken to prevent, it is clear that the moving rope as well, may perform an important part as a means of checking the velocity on the descent. On moderate inclines, where ordinary brakes are sufficient, the descent would be made naturally with the driving pulleys disconnected, and running freely along the moving rope held still. But if these brakes were not sufficient, it would only be necessary to tighten the clutches more or less to introduce a new resistance, which could be regulated at will, and which would have for extreme limit the slipping of the cable on the locked pulleys. At the same time, this expedient does not appear susceptible of frequent regular use, for it would have the effect of polishing the rubbing parts of the clutches, and of determining afterwards slipping under the action of the motors; but above all it would strain the cable, which must be preserved.

Altogether, the *Agudio* system, even in this first form, possesses incontestably, from the most essential point of view of the means of stopping, more varied and more powerful resources than the system with direct traction, and presents, on that account, more complete guarantees of safety; and if it is true to say that the situation is the same at the limit, that the train should suffice for itself and be stopped at need without the aid of cables, this extreme position, always critical perhaps on very steep gradients, is also less to be dreaded on the new system than on the old.

461. The system now occupying us, offers a remarkable example of the transmission of mechanical work to great distances by means of a cable animated by a speed purposely enhanced. There is thus, in this respect, a great analogy between M. *Agudio's* mode of traction, and a method of distributing of mechanical work, which has of late years received a great

development, especially in a land where the spirit of initiative and progress renders still more painful the blow which has violently separated it from France. It is that of which *Mulhouse* is the principal industrial centre.

It is well known that the transmission of work by cables running at a high speed under slight tension, is particularly due to M. *F. Hirn* of *Logelbach*, whose labors joined with those of M. *Stein*, of *Mulhouse*, have determined the principal elements of this ingenious and useful application.

The transmission by means of cables is only possible for distances somewhat considerable : 100 feet seems to be about the minimum; as to the other limit, 3.280 feet have already been exceeded, and nothing shows the slightest drawback in going farther. For velocity, that appears to be limited only by the centrifugal force of the pullies, and M. *Hirn* estimates that it may reach 100 feet a second.

The cables employed are always of iron wire or steel wire; this curious application comes in thus to form, within the widest limits, an admirable supplement to transmission by straps, which on the contrary are only applicable, as is known, to very small distances.

No known method for the transport of mechanical work is so economical, as much in respect of the cost of establishment, as in that of loss of work; after many observations made by the *Société Industrielle* of *Mulhouse*, that loss is only of some hundredths for a distance of several hundred yards, when the pullies are carefully fitted. The success of teledynamic transmission is a guarantee of the truly practical conditions, under which the motor rope of M. *Agudio* works.

The mode of construction adopted by this engineer for his ropes, is the one made use of by MM. *Hirn* and *Stein*. At *Dusino*, the motor rope was formed of four strands, each of four steel-wires 0,08 of an inch in diameter; each strand had a core of hemp, and the four strands were themselves twisted round a core of the same material, 0,24 of an inch in mean-diameter. This arrangement has been pretty general for a long time in cables for mines. Although increasing the diameter, the core seems to increase the flexibility. Weight of the lineal yard : 1 lb, 18. This cable was uncovered, the steel being harder than iron, wearing much less quickly. The adhesion cable, of iron wire, was composed of seven strands, without core, each of nineteen wires 0,08 of an inch in diameter, and twisted on a thick core of hemp from 0,51 to 0,55 of an inch in mean diameter.

The reduction of the weight is as that of the diameter, of much less importance for this cable than for the motor rope. Thus it was covered with

a tarred hemp covering; and the same motive led to the use of iron instead of steel.

462. We have dwelt on the *Agudio* system, such as it has been tried in Italy, more than is in general expedient to do in the case of processes which have not completely received the sanction of practice. But in this case, the exception is justified by the results of an experiment made under the most conclusive conditions; it is also justified by a chief consideration : the in sufficience of the other known solutions.

Without doubt at *Dusino*, the system was not on its real ground; for gradients of one in 37, there is no need of it. It is especially the solution of extreme gradients, but this experiment has not the less attained its end. It was necessary, above all, to see the mechanical combinations which constitute the system, at work, the play of which is independent of the inclination of the gradients. If it had failed at *Dusino*, it would have been condemned out-and-out, and no one would have dreamed of putting it to a new test, either on steeper gradients, or under analogous gradients. After so very complete a success as at *Dusino*, it seemed that a real application would not be long wanting. Several years have passed by however, and nothing has been done. It is not that opportunity has been wanting, but railway engineers have a difficulty leaving the locomotive.

If however they are reproached, at times justly so, with a little too much indifference with respect to new ideas; their position must be fully taken into account. For those who have no responsibility, it is easy and attended with no risk to act the generous part bringing forward the merit of useful inventions, and urging the application thereof. In case of want of success, if things have gone too far, silence covers a prudent retreat; but those who hold the reins are obliged to be more cautious. If fixed ideas, and settled views, dispose them but little to go into new things, it must also be admitted that their mistrust has often a more valid reason; it is that failure would involve their responsibility.

It is unfortunate for the *Agudio* system, that the trial on a large scale should not have been made under more favourable conditions, where it would have perhaps have been carried on longer, and been utilised for industrial freights. It would have been well also if the inclination had been pushed farther. If the experiment at *Dusino* was sufficient to allow the mode of traction to be judged of, it is not so with regard to the means of stopping, on extreme gradients which are the real foundation of the system. Therein lie questions of the highest importance, and all that can be said of

the solution, is that it seems to be arrived at. Practice must therefore (and this the inventor has long recognised) be appealed to again, either by a regular application, or by a new experiment, carried to the utmost extreme.

463. *Experiment at Mount Cenis.* — Two governments, France and Italy, Italian municipalities, and railway companies have combined for the cost of this operation, and Mount Cenis, from *Lans-le-Bourg* to the pass or (rather to refuge no, 20), was chosen by common accord, as the most favourable ground: there is no other in fact more appropriate for the establishment of a complete and conclusive experiment. The inclined plane, following nearly the general direction of the old road of the *Ramasse*, leaps at one bound, with an inclination that goes up to one in 2,6, the 1.762 feet difference of level between *Lans-le-Bourg* and the pass (Pl. LXXXVIII, *figs.* 1 and 2). It mounts up thus in 1,5 miles, that is to say with a mean inclination of one in 4,1, this mountain along the side of which *Fell's* line developed, with a length of 5.6 miles, its numerous sinuosities in order to offer for the locomotive a line on which it was able, strictly speaking, to draw itself and haul a weight equal to its own.

Mr. *Fell's* experiment was tardy, but this one is still more so; if the project, the execution of which has been still farther delayed by the disastrous events of 1870 and 71 could have been realised at the period when it was fully warranted, that is to say at the time of the *Dusino* success, we should now know what to think of the matter, without taking into account that the proceeding would have been useful in itself, and probably remunerative. The two systems, *Agudio* and *Fell*, put to the same problem, combating thus on the same field, for their respective principles, would have at the same time completed each other. The first leaving the passenger traffic to the second, would have had a special task, the raising of coals from *Lans-le-Bourg* to the pass, a work which *Fell's* line was incapable of doing, and the latter establishing, on the descent, the continuity between the French and Italian lines, would have permitted these coals to reach under comparatively economical conditions, the Italian markets, for which the double experiment would have been a real benefit.

The works, very inconsiderable indeed, had been actively pushed forward, and the formation level was already beginning to show, when the occurrences of 1870, forced them to be given up.

The principles applied at *Dusino*, and the mode of construction of the locomotor, raise no fundamental objection; but a new system, even long elaborated, is always imperfect and besides, the application itself of the principles, may and ought to be modified according to circumstances. Thus

on the incline of one in 37 at *Dusino*, the influence of the 20 tons weight of the locomotor was nothing out of the way. It would not be so on a gradient so incomparably steeper, such as the Mount Cenis one. In this case there is a main interest in reducing the ratio of the weight of the apparatus to the work it transmits in the unit of time.

On the other hand, if the adhesion cable, is a satisfactory solution, the best perhaps for moderate gradients, its breakage must always as has been said be provided for. The train can doubtless be attached to the rail of the line, by means of ingenious contrivances such as the *Croix-Rousse* brake (446) but from this main point of view, a central rail, very solidly constituted is the surest of all guarantees. Now as long as considerations of safety lead to its adoption, there could be nothing better than to take also the point of support for the traction from it, either utilising it under the form of a rack (433 and following) or, as Mr *Fell* does, obtain by an artificial pressure exerted on it, an adhesion more or less sufficient. The central rail thus becomes at once the perfect guarantee always indispensable, against the consequences of the breakage of any other part, and an *adhesion cable* which possesses its resistance proper throughout its whole extent instead of depending altogether on that of all the elements comprised between the fixed point to which it is attached, and the locomotor. Moreover, with the central rail, the curves are no longer limited by considerations of safety ; the connection of the locomotor with the line removes effectually all danger resulting from oblique traction on the cable, in case of it getting away from its guides.

464. *Locomotor of* 1867. — This substitution of the central rail for the adhesion cable had however already been adopted by M. *Agudio*, in his second type of locomotor constructed in 1867, and which was only able to be placed in the Exhibition a short time before the closing.

Figures 5 and 6 of plate XCI represent it.

We shall point out the features wherein it differs from the locomotor of *Dusino*, by going rapidly over the mechanism from the rope to the adhesion wheels.

1st. The two lines *c*, *c* of the motor rope, and consequenly the pulleys P, P, on which they wind are no longer placed between the rails, but outside. All the parts of the apparatus itself as well as the supporting and guiding pulleys thus find their place much more easily, in a less confined space.

2nd. The pulleys 4 ft, 6 only in diameter, are formed of a disc of iron plate; on its circumference are riveted two circular angle irons forming a

groove (g, *fig.* 6) in the bottom of which are driven in by hammer two hemp ropes.

3rd. The adhesion drum is replaced by the six horizontal wheels ρ, ρ, ρ, (*figs.* 5 and 6) pressed against the central rail C. The two sides of the apparatus, driven by the two lines of rope, are independent one of the other, save the concordance, established as we shall see presently, of their action on the two groups of adherent wheels.

4th. Gear-work is substituted, on the side of the ascending line of rope, for friction. Springs interposed between the rim and the friction circle, allow the effort which the pulleys can transmit to the shaft to be limited with certainty, and consequently the strain to which the rope may be subjected.

5th. On the side of the descending line of rope, the general arrangement is the same. The two pulleys drive also, by toothed wheels, a wheel contained between them, and which has thus a rotation in a direction contrary to that of the wheel driven by the ascending line of rope.

6th. These contrary rotations ought to have the same angular velocity, in order that the transmission of movement to the adhering wheels vertical and horizontal, may be effected on the two sides by similar mechanism. Hence, for the diameter, conditions analogous to those indicated for the original locomotor, with adhesion cable.

On the side of the ascending line of rope :

V being the absolute velocity of the cable, v that of the train, R the radius of the pulley P, r and ρ those of the pinion p and of the wheel E, the angular velocity of the axis O is

$$\frac{V-v}{R}, \quad \text{and that of the axle A,} \quad \frac{V-v}{R}\,\frac{r}{\rho}.$$

On the side of the descending line of rope :

r' and ρ' being the radii of the pinion p' and of the wheel E′, the angular velocity of O′ is

$$\frac{V+v}{R}, \quad \text{and that of A}', \quad \frac{V+v}{R}\,\frac{r'}{\rho'}.$$

The condition of equality is thus :

$$\frac{r}{\rho} : \frac{r'}{\rho'} = \frac{V+v}{V-v};$$

If, for example, it is desired to make the velocity V, of the rope, three times that of the train, v, (the ratio adopted in the locomotor in question), we have $\frac{r}{\rho} : \frac{r'}{\rho'} = 2$, a condition satisfied by making $r = \rho$, $r' = \frac{1}{2}\,\rho'$, that is

to say by giving, on the side of the ascending line of rope, the same diameter to the two pinions p, p, and to the wheel E; and on the side of the descending line, a diameter twice as great to the wheel E′ than to the pinions p', p'.

7th. From these two shafts A, A′, the rotation ought to be transmitted not only to the six horizontal wheels which press symmetrically on the central rail, but also to the four wheels which carry the apparatus. It would be wrong to neglect the adhesion due to the weight, when it is so easy to utilise it.

From this point, the apparatus presents a great analogy with the 2nd type of the Mount Cenis engines (428). The movement of rotation is first transformed, on each side, into a rectilinear alternate movement; the crank M and the rod B acting on a pretty long crank, impart a simple oscillatory motion to the shaft S, and it is this shaft which drives, on the one part, by the rod B′, the three horizontal wheels coupled together, and on the other, by the rod B″, the two carrying wheels on the same side, similarly coupled together.

The two connecting rods B′, B′, driven by the cranks μ, μ, cannot be articulated therewith. Each of them is connected by an articulation ω to a frame guided by the slides g, g, and to which a backward and forward motion is given by the crank μ, the extremity of which plays freely in an opening in the frame.

The concordance of the movement of rotation imparted, on the two sides of the machine, to the two systems of wheels either carrying or horizontal, under the action of the velocities, equal but contrary of the two shafts A, A′, results from the crossing of the oscillations of the two cranks M′, μ, keyed on the shafts S, S′; a relation which results itself from the rectangular position of the cranks keyed on to the prolongations of the carrying axles.

To prevent, in the case of starting on the dead points, the crossing (359) of the two coupling rods of the three vertical shafts of the same side, the latter are connected together by a toothed wheel keyed on to each of them and by the two pinions π, π. This connection insures the concordance of the directions of the three rotations. It is still the old contrivance (428) to which is substituted the new solution of the *Cantagallo* engines (435).

The pressure on the horizontal wheels is applied, as in the Mount Cenis engine, by the intermedium of springs.

The bearings of the vertical wheels are established, on each side, on a frame K, K, which can slide on the cross-bearers T, T; by acting on the crank Q, the driver brings together the two frames which act on the lower

bearings of the shaft by means of springs with staged plates r, r, r, applied by their middle to the bearings.

This locomotor weighs 8 tons; two apparatuses coupled give thus, at 5 tons on each of the twelve horizontal wheels, a total adhering pressure of $2 \times 8 + 5 \times 12 = 76$ tons, and an adhesion of $\frac{76.000}{10} = 7,60$ tons.

M. *Agudio* establishes that, on a plane of six miles and a quarter on one in 12,5, and half its length with curves of 220 yards radius, a gross train of 86 tons, or 70 tons of useful load, would be hauled at a speed of six miles and a quarter an hour, by a rope running three times as fast, weighing 2 lbs to the yard, having a maximum strain of 11 tons on the square inch, and that the useful effect would be 72 per cent. Without regarding this result as rigorously exact, it brings out the property of the system of admitting at the same time, a great length, sharp curves, and heavy incline. The useful effect would rise (much less rapidly however than with the locomotive) if the inclination were lowered; but this consideration would often be secondary; the inclination, easiest and most economical on the ground, would generally be preferred; and the system should find its application more on gradients steeper, and even by far, than one in 10, than on flatter ones.

As to the length, it should, also, be determined less by the consideration of the useful effect, than by the requirements of the traffic; the impossibility of sufficing for that, by a single plane getting over a great amount of height, might lead to a division of the train, under circumstances where in other respects one single plane would be preferred.

The safety brake is an apparatus with jaws M, M, similar to that of the Mount Cenis engines; on the descent, the cable might be made use of by making the clutches act; but it is far better not to work the cable, when it can be avoided.

The compression of the air, so well made use of on inclines worked by locomotives and rack (437) might be equally applied to the locomotor. But if it is quite natural to make use of the engine cylinders as means of stopping on the descent, it would be objectionable, especially from the point of view of increase of weight, to introduce cylinders solely for stopping purposes. With a properly constituted central rail, direct means ought to be sufficient.

Pawls suitably arranged are sufficient however to prevent running backwards, in case of the rope breaking on the ascent.

465. *Modifications of the system.* — In 1870, a thorough study was com-

menced with the co-operation of the firm of *Cail* and *Co.*, who undertook part of the work; a co-operation the more satisfactory that the construction of the last engines for the trial line from *Lans-le-Bourg* to *Susa* (428) had prepared their engineers for that of the locomotor adopted to the central rail. But there was soon no question of peaceful experiments; in the workshop as in the field, productive work had to be put aside.

Resumed at last, this study led to a modification which touched the very essence of the system; it consists in giving up one of its principles, that is to say of the motive action of the descending cable and consequently of the corresponding reduction in the section of the cable. That which results from the amplification of its velocity alone remains. It is a pity to leave out in an experiment of that import, one of the essential features of the system it was the question to test. At the same time it must be allowed that there are serious if not altogether overpowering reasons for this step. With one single motor placed at the bottom of the plane, at *Lans-le-Bourg*, the expenses and difficulties are obviated, of the establishment and maintenance of the upper motor, under conditions very unfavourable as regards economy and climate.

As a partial compensation, the direct traction of the single working line of the rope is profited by, while in the complete system the couples alone are added together, the two contrary tractions neutralising each other.

By fully employing the second principle, that is to say the relative acceleration of the cable, the advantage which characterises and sums up the system, that is to say the reduction of the weight of the rope, is still obtained in a satisfactory degree; and on such enormous gradients as that of *Lans-le-Bourg* the item of the direct traction, although reduced by the very fact of the high speed of the rope, is not without importance. It furnishes a fraction of the total effort, equal to the ratio of the velocities of the train and of the cable, and reduces by so much the effort on the central rail. It will be remarked besides, that the one motor would be better placed, from the mechanical point of view, above than below, since the length strained of the cable varies in the first case from L to zero; and, in the second, from 2L to L, L being the length of the plane. But as the descending line of rope is straight and supported only by pullies very far apart (87 yards), as in ordinary teledynamic transmissions, the passive resistances arising from that line of the rope, are much less than those of the line which follows the sinuosities of the road, the aggravation is inconsiderable.

Another modification naturally derived from the first consists in the

substitution for one single motor rope, of two ropes, each driving a pair of vertical pullies, one on the right, the other on the left of the locomotor. The latter is thus solicited symmetrically on both sides, instead of being subjected as with a single cable, to the action of a couple which tends to pivot it round an axis normal to the line: a secondary advantage, however, above all with the central rail, which efficiently opposes the action of that couple.

With two ropes, which, with equal section, have less stiffness than a single rope, we approximate to the substitution of a flat rope for a round one; a flat one would be of very difficult application on inclined planes. Moreover, the breaking of one rope would not interrupt the service; the other one insuring the continuity thereof, on condition of course, of reducing the weight of the train.

Let us follow the path of the cables. From the driving pulleys P, P, driven by the turbines (Pl. LXXXIX, *fig.* 1) they rise (*figs.* 10 to 12) straight up, pass over the return pulleys S, S, on the summit, descend following the inclined plane, winding round the pulleys of the locomotor, pass over those of the strainers T, T (*figs.* 4 to 6) and close the circuit by passing on to the pulleys of transmission π, π (*figs.* 1 to 3).

466. *Double rack, and permanent way.* — The Mount Cenis inclined plane presents another main modification; on such inclines, in order to transmit the enormous effort which the ascending traction requires, and especially prompt stopping on the descent, the adhesion is not enough; if it was believed that the pressure on the central rail was sufficient for everything, the experiment of Mount Cenis has proved how much that opinion should be revoked. On inclinations such as that of the plane in question, the insufficience and incertainty of the adhesion must be got rid of; a fixed point must be relied on, that is to say the rack come to; but it is not in this case applied under its simplest form, as at Mount Washington and the Rigi; the necessity of distributing the effort of traction over a pretty considerable number of points of support, led to keeping the general arrangement of the mechanism, that is to say, the horizontal wheels, but gearing into a double rack. It is formed (Pl. LXXXVIII, *figs*, 3, 4 and 6) of a ribbon of steel 0,47 of an inch thick and 4,72 inches folded backwards and forwards on itself and kept in place by two cheeks γ, γ (*figs.* 4 and 6) in Ω iron, fastened by strong rivets *r*, *r*, going through the piece at the bottom of each tooth formed by the bends of the ribbon. The latter cut out of straight bars 5 ft, 9 long is bent over gradually by

the curving machine and finished on a swage which gives the teeth their exact shape. Its length becomes then reduced to one-third, or 1 ft, 97. Three of these bars, taken by the two cheek pieces of 5 ft, 9, form the element of the rack, and the length thereof being so short allows the curves of 164 yards radius, of which there are many on the experimental plane, to be replaced by polygons having these pieces for sides. This rack is fixed by thick bolts *b*, 1 ft, 48 apart, each of which takes the place of the corresponding rivet, on the longitudinal timber L, itself fastened to each of the cross sleepers by two bolts B, B.

The manner in which the pieces of the rack are joined together is an important point. In each of them the ribbon comes at one end to 1 foot short of the end of the cheeks, while at the other end it projects that amount beyond the end of the cheeks. The fitting in and riveting is done by leaving a play of 0,06 of an inch between the consecutive cheek pieces; to this joint of the cheek pieces one of the thick bolts *b*, *b* corresponds. There is thus between the consecutive pieces of the rack a sort of fishing, and the ribbon gives to the variations of temperature by the slight deformation of its bends. On each side of its joints the ribbon is fastened by three small rivets *s*, *s*, *s* on the big rivet *r*, to prevent the opening of two contiguous teeth.

The rack in place weighs 120 lbs to the yard.

This most essential part is worthy of remark. The form of a ribbon bent backwards and forwards is a very lucky thought, and the idea of the inventor has been very well carried out by MM. *Brunon* brothers, mechanical engineers at *Rive-de-Gier*. The cheeks γ, γ between which the teeth of the pinions gear, attach the locomotor invariably to the line; they serve also, on the curves, to guide the apparatus, by the intermedium of friction rollers *f*, *f* (*figs.* 4 to 6) which surmount the pinions.

The teeth involve considerable passive resistances, which do not doubtless reach those resulting, with friction wheels, from the enormous pressure necessary for developing adhesion, besides which is quite insufficient.

With the rack, the number of wheels can be reduced, for the same amount of effort to transmit; moreover, the apparatus for the pressure of the wheels, on the central rail, disappears; and the brackets of the vertical shafts become fixed, at least as long as the rack has not to be quitted and taken on to again.

Permanent way. — The line is on the usual gauge, with *Vignoles* rails of 34 lbs to the yard, fastened by fang bolts to the cross sleepers 11 ft, 8 long and bound together as at the Rigi by two lines of longitudinal timbers;

these latter are mortised to receive the posts, let 2 ft, 62 into the ground, which support the gallery of sheet iron and timber, covering the whole of the incline plane.

In execution, this plan was modified, in order to utilise short lengths of timber from the *Fell* line. The interval between the long cross sleepers was carried to 5 ft, 90 from centre to centre; it received two struts, inclined symmetrically to the axis of the line, attached by their upper ends to the central longitudinal timber, and supported by the other on the cross sleeper against the side longitudinal.

Supporting pullies of the rope on the permanent way. — M. *Agudio* has given up for the construction of these pullies, *Atwood's* system of suspension, which he adopted at *Dusino*. The very difficult climateric conditions under which the new apparatus had to work required more simplicity.

The inventor devoted himself to insuring the perfection of the lubrication, and preventing the entrance of water and dust into the boxes.

In the straight line pulleys, that is to say with axis horizontal, the lubrication is effected by a ring α (*figs.* 3 and 4, Pl. LXXXVIII), simply placed on the journal φ, φ, and which the latter turns round with it; the ring, plunging into the reservoir of oil, takes it up and puts it on the journal.

In the curve-pulleys, that is to say with vertical axis, this axle o, o (*figs.* 6, 7 and 8) turns with the cylinder R on a footstep which a lower nut e allows to be set up to allow for wear.

In the two types of pulleys, the grooves on which the cable takes, are fitted with leather straps on edge; the gripping of the rope on these prevents all slipping, and renders its wear very slow.

467. *New locomotor.* — Let us now return to the locomotor, much simplified, and become symmetrical relatively to its mean longitudinal plane.

The apparatus consists essentially in this (Pl. XC, *figs.* 1 to 5). On each side, a pair of pulleys of large diameter (8 ft, 20) a, a, receives the movement of an endless rope, and transmits it by conical gearing b, c to the horizontal wheels d, d.

The adhesion of the carrying wheels is not utilised.

Let v be the velocity of the train, equal to the velocity at the original circumference of the toothed wheels d, d; r the radius of these wheels; R the radius of the pullies; q the ratio of the conical gearing b, c. The velocity

at the circumference of the pulleys is $v\,\frac{R}{r}\,q$ and the velocity of translation V of the rope $= v\left(\frac{R}{r}\,q + 1\right)$.

For $R = 4{,}10$, $r = 1{,}21$ feet, $q = \frac{2{,}10}{1{,}81} = 1{,}165$, we have $V = 5v$.

The clutch, one of the most necessary organs as a guarantee against any excessive strain brought on to the ropes, is naturally retained in the new apparatus. The conical wheel b is not keyed on to A, the friction wheel g, keyed on that shaft, is solidly connected at will, with b by means of six segments pressed by so many rods h, h (*fig.* 2). The driver works these by the shaft k, the rod m (*fig.* 2) and the lever jj' oscillating round the fixed point j', which works the socket piece i.

The two shafts k of the front and hind clutches are coupled by a third shaft l worked by the handle P (*figs.* 3 and 5) by means of which the driver manœuvres the four clutches at once.

Sockets with reverse threads allow the lengths of the rods h and m to be adjusted: an adjustment which is necessary to take up the wear of the friction segments, and insure the simultaneous action of the four clutches.

The independence of the four apparatuses of transmission of the power, of the large pulleys with toothed wheels, fixes an evident limit to the pressure which each tooth of the rack may undergo. It is that which corresponds to the slipping of the rope on a pulley over which it takes only one turn.

Brakes. — 1st. The most energetic is the jaw-brake, seizing by long iron shoes, r, r the wooden longitudinal, the support of the central rail, and the levers of which S, S are worked by screws with reverse threads t, t (*figs.* 1 to 3).

2nd. Two brakes, independent and with wooden blocks n, n, acting on the cylindrical rims α, α, α, attached to the conical wheels c, c (*figs.* 1, 2 and 3). The blocks n, n are coupled together two and two by the cross pieces o, o (*fig.* 4), taken at their middle by a shaft p, bearing two threads inverse ways, and the rotation of which is produced by the handle G (or R behind), the endless screw θ, and the wheel q. These two brakes allow the locking of the wheels d, d... to be obtained, and consequently stoppage produced as at the Rigi (435).

3rd. The friction clutches would be at need, as has been already said (458), a powerful brake. Before descending, the cables would be moored at the summit by stopping clips q, q (*figs.* 10 to 15, Pl. LXXXIX), and the pres-

sure of the clutch blocks would be regulated so as to allow the pulleys to turn.

The locomotor is provided as well, with four safety pawls v, v... (Pl. XC, *fig.* 1) acting like those of capstans. They run over on the ascent, the teeth of the double rack, and would prevent a retrograde movement in case of the breakage of the ropes or one of the pieces of the mechanism.

The pawls are connected together by a rod traversing the two levers x, on each of which acts a spring z which keeps the pawls applied to the teeth of the rack.

The play of the pawls should be checked on the descent. Such is the object of the fly wheel T (*fig.* 3), and of the conical gearing ω, w. The nave of the wheel w is run on to the rod y, which, drawn backwards, causes the four pawls to turn, and thus keeps them off the rack.

In order to avoid more surely the pawls getting into gear during running, which would at the very least cause breakages of the parts, it is necessary in order to work them, to get down from the locomotor. This is the motive for the position of the fly-wheel T, which is inaccessible from the platform P′.

The frame of the locomotor is formed of a sort of box of plate iron, at the same time rigid and light; the brackets of the shaft and of the pulleys are supported by strong brackets K, K; and the arrangement of the frame assures to the double brackets of the vertical shafts B, B, points of support of solidity beyond all question.

The suspension, necessarily with very small play, is reduced to a couple of small *Belleville* springs β, β (*fig.* 1) let in between the supports of the inside longitudinals and each axle box; nuts below γ, $\dot{\gamma}$, allow their tension to be regulated.

Placed on the platform, at the centre of the apparatus, the driver has under his hand the means of working the different organs. The access to this platform is facilitated by two foot plates with steps Q, Q, and a handrail so as to keep clear of the parts in motion.

It will be remarked (*fig.* 1) that there is a considerable amount of overhanging at the front of the apparatus. The centre of gravity is much nearer the front axle than the hind one, and consequently the statical distribution of the weight, on a level, very unequal. The object of this arrangement will be at once understood: 1st, to compensate, in running (277) for the influence exerted on the distribution by the couple of the effort of traction, an effort enormous under the conditions in question; 2nd, to so arrange that on the maximum gradient, the vertical from the general centre

of gravity passes nearly through the middle of the distance of the points of contact of the wheels and the rails. This can be neglected on inclinations accessible to locomotives, but is very important on gradients of one in 2,6.

The two ropes, 0,90 of an inch in diameter, were furnished by *Newall and Co*, of *Newcastle*, manufacturers of the steel cable used at *Dusino*, and which gave great satisfaction.

468. Plate LXXXIX, *figs.* 1 to 15, represents the mechanical installations at the two ends of the plane, that is to say, on the one part, the turbines, the transmissions and the strainers established at *Lans-le-Bourg*, and on the other, the return pullies at the summit.

Hydraulic establishment, transmission and strainers. — At the height of 459 feet above the foot of the inclined plane, M. *Agudio* has placed in the very steep deep banks of the Chargeur torrent a dam holding back 530.000 cubic feet of water. A conduit C, 470 yards long, formed of plate iron tubes 2 ft, 16 in internal diameter, the thicknesses of which gradually increase from 0,16 to 0,39 of an inch, has been set up on the sides of the mountain to connect the reservoir with the hydraulic establishment.

A sluice placed at the upper end of the conduit, allows the water to be discharged therefrom during the cold nights in winter.

This conduit runs into the building, branching off through two cast-iron elbows K, K, 1 ft,64 in diameter, internally, each of which is supplied with a sliding valve *u*, *u*, which allows the two turbines to be used either separately or both together.

The turbines *t*, *t*, on *Girard's* system, with horizontal axis, are 5 ft, 90 in diameter. Their distributors are worked by a piston ω, acting by the effect of the column of water, in order to render the command of the apparatus more prompt. A centrifugal force regulator indicates the velocity the ropes are running at, and the driver can regulate the running of the turbines and at distance that of the train.

The tangential velocity of the turbines is about 98 feet per second. The intermedium of the gear work *p*, *o*, reduces this velocity on the ropes to about one half.

This important hydraulic establishment, serving to create a force of 1.000 horse-power, was constructed in the workshops of *Roy and Co*, at *Vevey* (Switzerland).

Dynamometrical strainers. — At the lower extremity of the inclined plane, each of the two endless ropes passes over a tension apparatus (*figs.* 4 to 9) which does not move freely as at the inclined planes of *Liége*, under the

action of a counterweight; it is simply a sledge with a short run acting on a graduated dynamometer *d*, *d*, and formed of couples of *Belleville's* springs. The indication of this dynamometer is the object of the arrangement in question, for it is the weight of the long stretches of 262 feet of the rope itself on the teledynamic line which gives it the permanent tension necessary for the transmission. To compensate at need for the elongations, use will be made of the strainer θ, θ, analogous to that of a locomotive coupling. The side chains *l*, *l* (*figs.* 4 and 5) allow the chain of the dynamometer to be unhooked, either to shorten or lengthen it by a link, or to repair it, etc.

469. *Conclusions.* — Taken altogether, the *Agudio* system is not a simple improvement; it is really a new solution, adapting itself to circumstances, forcing back in the most unlooked for manner the limits of gradients, of radius of curves and of length, within which inclined planes with direct traction were kept; planes costly on that very account to establish, and not less costly to work. Thus they are rejected, and with reason, by seeking to obtain, often with every sort of sacrifice, a line on which the locomotive may still drag itself along with a shadow of a load. Although the delay in the definitive proof to which the *Agudio* system was bound to be subjected, is regrettable, enough is known of it already, for engineers having a difficult passage to deal with, or those who have for task of constructing a railway economically in a difficult country, cannot overlook this solution.

Not that it is however, destined to effect, as some have thought, a complete revolution in the conditions of crossing mountain chains by railways. It will often allow their traces to be thoroughly modified in their details, but not, I think, in their essential features. It will simplify, and that will be already a great deal, the conditions of access on the flanks of the great chains, but it will not change, at least for important lines, the height of the crossing of summits, a height, the maximum of which appears to be in every case an absolute limit imposed by climateric conditions, both independent of the mode of traction, and of the inclination it allows for the gradients.

If tunnels of from 7,5 to 8,75 miles attacked only by the two extremities, which were considered almost impracticable before the admirable boring of Mount Cenis, are now-a-days within the range of possible operations, it is still however at a great expenditure of time and money. But on the other hand, have the consequences been fully estimated of a trace rising in the Alps to 7.000 feet and more, to cross the passes in the open, or only 5.000

or 6.000, instead of about 4.000 as at Mount Cenis, in order to reduce the length of tunnel to 3 or 4 miles for the most favourable traces?

At such heights, the ground disappears during whole months under a depth of snow of several yards; storms occur, and avalanches fall. This is met to a certain extent by covering over the line, or indeed by a tunnel at only a few yards under the ground: an idea recently broached, and practicable perhaps in some cases. But in spite of all, in spite of the aid of a numerous and costly staff, could long interruptions of service be helped? And is reckoned for nothing, the increase of development, and especially of height to get over, and consequently mechanical work to expend, and what would often be more serious still, the greater length of journey involved by an excess of height of 2.000 or 3.000 feet?

Without doubt, the execution would be more economical, prompter especially. People are in a hurry to get a line open, and rightly. Let them, then, do on a large scale, if possible, what Messrs *Latrobe*, *Ellet* and so on have done, that is to say make temporary passages, if not entirely in the open air, at least with a reduced length of summit tunnel; but a hurried conclusion should not be drawn, from the easy success of some passages of this sort, over summits of no great altitude, that it would be the same with those striding over the Alpine passes. If such a solution be admitted as a permanent measure, it can only be for lines of secondary importance, where economy in working has to be sacrificed to that of construction.

470. *Project for crossing the Simplon.* — The engineers who did not shrink, at least on paper, from tracing out lines in elevated regions, while they had yet no other resources than the ordinary locomotive, with gradients excessive for it, although relatively flat, have come back, with redoubled confidence as may be conceived, to the same solution, in the presence of systems which admit strictly speaking, as that of Mr. *Fell*, very much steeper gradients, as that of M. *Agudio*, inclinations so to say unlimited.

The company of the Italy line had presented a complete project of the crossing of the Simplon by a locomotive line; a project the bases of which, according to us, were perfectly inadmissible (the gradients reached one in 25), but which these bases accepted, seems to have been studied with much care (Pl. CIX, *figs.* 1 and 2).

Taking up this project with gradients of one in 12,5, the total development from *Gliss-Brigg* to *Domo-d'Ossola*, becomes reduced from 50 miles to 30. Of the numerous shunts resorted to in the primitive project, one

only remains; the altitude reached is besides the same [illegible], the summit tunnel, 2,89 miles in length, being common to both traces which on the southern slope, are very much the same.

471. *The limit of altitude is very nearly independent of the mode of traction.* — Reserving the general question of the limit of the altitude [illegible] it is expedient to fix, the comparison of these two traces brings well [illegible] the services which may be hoped for, from the *Agudio* system applied to a very uneven country; especially if it be considered that the primitive trace brought in exaggerated elements, such as numerous reversing places, and gradients altogether excessive for the locomotive. But, once more, the main objections which these upper crossings give rise to, are independent of the mode of traction; to stop at this level of about 4.000 feet, above which the working would be hampered with all the difficulties of Alpine inclemencies, a very heavy burthen must be accepted, that of the execution of the great tunnel. To enable this burthen to be borne, there must be traffic insured to the railway and if that be not the case, it must be refrained from. We have already said, but may as well repeat it: a defective trace, incomplete, inflicting on the working a considerable increase of expense and loss of time, would have precisely the effect of driving away from the best situated crossing, a traffic of which a line better laid out, and more in keeping with its naturel importance, would have insured the entire possession and normal development.

If to the objection of the cost of the great tunnel, it were wished to add others taken from among its disadvantages from the point of view of working, it would be easy to dispose of such. First of all, if tunnels of 8 and 9 miles have been hitherto unexampled, it was at any rate something to have tunnels constructed of 2,75 miles as at *Blaisy*, of 2,90 miles as at *la Nerthe*.

It is true that several of the numerous shafts which served for the boring have been kept, and contribute to the ventilation, the presumed insufficience of which was one of the principal objections against tunnels of very great length, and without shafts.

But as we have seen (370 and following) the conditions of ventilation are very complex, and its want is more seriously manifested in certain short tunnels than in others which are longer; and besides, admitting this objection, would the upper traces be free from it? Certainly not.

From about 4.000 feet, the line must be covered over in the Alps by galleries capable of resisting the weight of the snow, and at certain points, the shock of avalanches.

The line is thus, above that height, in one continued tunnel.

On the *Fell* line, the ventilation was very insufficient; so much as that the passengers, instead of making up thereby for not seeing one single point of the grand scenery they were passing through, were condemned also to breath nothing but suffocating air. Very far from reducing the inconveniences wrongly complained of as attending passages through mountains, the higher crossings increase them remarkably, on account of the much greater length of the covered portion, and of the much more decided insufficience of the natural ventilation.

The covered galleries on the Mount Cenis line were in masonry on the points exposed to avalanches, and elsewhere either in sheet iron circular roof with wooden frame, or in timber with ridge and two gutters. The sheet iron galleries, which were lightly constructed did not stand on the points where the accumulations of snow form, between *Lans-le-Bourg* and *St. Martin*, the most exposed section to snow and wind; the combined action of which had completely destroyed the sheet iron galleries for a length of 850 yards. With this exception they generally stood well.

During the winter of 1870-71, the stoppages in the running of the trains were produced principally at these breeches, six in number, which occurred at the most exposed points. Two other points also gave rise to interruptions of the service on account of the piling up of the snow, one on a length of 875 yards at the beginning of the Mount Cenis plateau, the other of 437 yards, at the other end of the plateau, where the covered galleries of the Italian side began.

As to the plateau itself, for a length of 2 ½ miles, the snow lies for a depth often considerable, but it is not produced there by the wind; so that a snow plough driven by an engine was generally sufficient to clear the line.

The interruptions were not frequent, but they sometimes lasted during several days. Thus from the 6th to the 13th Feb., the line carried no passenger.

It took only letter bags, which a train took as far as the line was practicable, and thence they went on either by sledge or on men's backs.

Similar occurrences would be disastrous on a line of great traffic, and they would have to be averted at any price; this could no doubt be managed by giving the galleries the necessary length, and constituting them solidly enough to resist the snow, the avalanches, and the wind; but the annual expense would then reach a figure which, without being comparable to that of the tunnel proper, is often put too low. But what we

would point out is that, leaving the question of expense on one side, the so called open air crossing, suffers in reality, and in a much greater degree than the passage *through* the mountain, some of the drawbacks, complained of in long tunnels.

This is only, however, a secondary side of the question. What is really weighty, against the higher crossings, what ought to exclude them at any rate from important lines crossing the great chains, is the increase of development, of height to get over, of the length of the journey, of the work of the haulage, without reckoning the works, which are put at far too low a figure, necessary to insure regular working in the middle of the region of storms.

Whatever may be the system adopted, if it is desired to keep the locomotive at any cost, if fixed motors under one or other of the forms, be adopted, great care must be always taken not to put the rails of great lines, in our climates, higher than 4.000 feet thereabout; and in that case, the long tunnels must be resolutely adopted; otherwise a fine and grand experiment would perhaps be made, like M. *Fell's;* a permanent railway would not be made capable of its work. Certainly, up to this altitude of about 4.000 feet, and indeed far below, the difficulties are great enough for the steepest gradients and appropriate modes of traction to be quite as indispensable as in the upper regions, which one should not aspire to contend with the tempest for.

As long as the height is not too great, the snow is an obstacle much less severe in the mountains, where the line runs more frequently along the flank, than in certain planes. The striking example of the plain of *Wagram* is known, where it was necessary to protect the Northern railway, on each side, by enormous banks, which gave the line the appearance of being in a long cutting. Interruptions in the service are not rare, on the *Orleans* lines in the plains of *la Beauce*, on the Midi in the *Narbonne* district, etc.

On the Brenner, there was not a single interruption during the rigorous winter of 1869. The snow plough had only to pass along once; while it was at work very frequently on the other lines of the South Austrian system.

The Italian commission charged with the examination of the different systems of traction, compared, in its report already referred to (*), the *Fell* and *Agudio* systems; they consider (*p.* 199) that the choice between these systems is a question of local conditions; that if there exists, as at Mount Cenis, a road adapted for the application of the *Fell* system, that should be

(*) *Ferrovia delle Alpi elvetiche, progette di lege, documenti giustificativi. Firenze,* 1866, p. 189.

preferred. We are far from sharing this opinion, which the study of the working of the Mount Cenis line does not corroborate. According to the commission, the *Fell* line has less to fear from the snow than the *Agudio* one, which is compelled to keep its fixed pulleys free. They forget that in the upper regions the *Agudio* line has to be covered over, as well as the *Fell* one; and as the essential character of the first is only to have a relatively short development, the argument brought forward by the Italian commission, in favour of the *Fell* line, must evidently therefore be turned against that system. Moreover, in the relatively short galleries of the *Agudio* line, the passengers are not as in the *Fell* line, plunged into an atmosphere already vitiated by the gases of combustion and steam.

The commission acknowledges besides (*), that the *Agudio* system remains the only one possible, if recourse must be had to inclines steeper than those admitted by practice for locomotive traction; which amounts simply to the exclusion, and on just grounds, too, of the inclined plane with direct traction. But if, as appears probable, the commission regarded the Mount Cenis experiment as proving that gradients of one in 12, are practically admissible on a locomotive line, we should be farther than ever from partaking of their views. That such gradients are strictly speaking possible, yes; but practical from an industrial point of view, certainly not.

For the great line of Mount Cenis, they luckily refrained from going up as high as these gradients of one in 25, one in 20 even, so readily accepted by engineers who pin too much faith on the promises of engine-builders. One in 33 is adopted, and that is too high. It is true that the fashion is at present, to make out the passage of Mount Cenis (or rather of Mount Frejus), as destined to a speedy collapse; or rather that the future, to which it had grounds for looking forward they say. If it did not exist (and it is very fortunate for France that it does exist), its turn would come, but it is not, without doubt, under existing conditions, the one that would be commenced with. It must be fairly acknowledged that, two years after the completion of the great tunnel, the traffic had not yet attained the development expected, and that this gigantic work is up to the present time but indifferently utilised. But great streams of traffic are long in establishing themselves, and here, that tardiness is enhanced by peculiar difficulties: the Mount Cenis traffic will overthrow those obstacles, and will profit by the large channel opened for it at such great cost.

The *St Gothard* crossing, the rapid execution of which seemed insured

(*) *Ferrovia delle Alpi elvetiche, progette di lege,* pp. 199 and 200.

by the cooperation which Germany managed to obtain on the part of Italy and Switzerland, presents more favourable conditions as regards trace; maximum gradients of one in 40, excepting, at most, one in 38 for a short distance on the southern side between *Biasca* and *Lavordo;* curves of 328 yards radius, maximum altitude 3.730 feet. These are the conditions of the Brenner (412), excepting as to the greater height of the latter (4.485 feet). The tunnel from *Goschenen* to *Airolo* will be, it is true, 9,26 miles long, but with an incline of one in 149 only from the northern end to the middle, and one in 1.000 from the middle to the southern end.

At the Luckmanier (the execution of which, by the way, seems to be put off indefinitely) M. de *la Ricca's* project, modified by reason of the success of the boring operations at Mount Cenis, involves a tunnel much longer still, 10,81 miles, coming out into the valley of the Rhine, at *Dissentis*, at the height of 3.615 feet, and in that of the Ticino, at 2.986 feet. Accepting this enormous tunnel, the trace is almost an ordinary one, and capable of fast trains.

The Splügen would require a still longer tunnel although with an altitude somewhat higher. By rising up to 4.413 feet, with gradients reaching one in 28,6, the length of the tunnel would be reduced to 6 miles; but this would be certainly too dearly paid for.

If, like MM. *Beckh* and *Gerwig*, the principal promoters of the Saint Gothard project, engineers now-a-days are more and more united as to the absolute condition of moderate altitudes for the crossing of the great chains, there are still however, some dissentients. A line of extreme importance for Austria, that from *Innspruck* to the Lake of *Constance*, crosses the chain of the Alps, and Mount Arl seems naturally pointed out as the crossing point. According to the project of M. *Thömmen*, who is known by his fine works at the Brenner, the line would pass in the open, at the altitude of about 5.900 ft, which it would reach by gradients of one in 25 and one in 20, worked by enormous *Fairlie* engines; but the government seems to have taken, and very wisely according to us, the opinion of the partisans of moderate altitudes and gradients.

In order to limit the inclinations to one in 40 (or one in 38 at need, on some points), and curves of 328 yards, MM. *Beckh* and *Gerwig* have been obliged to have recourse to every means of development. M. *Wetli* proposed reversing, reducing the gradients to one in 67. MM. *Beckh* and *Gerwig* do not absolutely reject this expedient; but they reject the pushing the train from behind, which involves the operation of putting the engine at the head of the train.

It would be much simpler and much surer to have an engine in front and one behind; an arrangement which so necessary, as we have seen, on steep gradients, and which is perfectly suitable with reversing planes.

The engineers prefer, to zigzags, spirals, or rather helices, with an inclination of one in 40, on vertical cylinders 338 yards in radius, and naturally for a great part, in tunnel.

432. The following table gives the principal elements of the St Gothard, Luckmanier, and Splügen projects, elements many of which, as need scarcely be said, are capable of modification more or less.

	ST.-GOTHARD. — Bellinzona to Fluelen.	LUKMANIER. — Bellinzona to Coir.	SPLÜGEN. Antonini. — Colico to Coir.	SPLÜGEN. Commission — Colico to Coir.
Total length	68,5 miles	80 miles	64 miles	67 miles
Length of levels	8,5 »	3,5 »	5,6 »	5,7 »
Maximum inclination, South side	one in 37.7	one in 40	one in 38	one in 40
Maximum inclination, North d°	one in 40	one in 54	one in 39	one in 39
Length of gradients of one in 40 and above	35,2 miles	8 miles	28,5 miles	29,9 miles
Length of gradients between one in 40 and one in 66	1,0 »	21,8 »	3,0 »	7,2 miles
Height at the south end	741 feet	741 feet	672 feet	659 feet
Height at the north end	1437 »	1919 »	1656 »	1643 »
Height at the south end of great tunnel	3707 »	3360 »	3701 »	4087 »
Height at the north end of great tunnel	3642 »	3615 »	3629 »	3717 »
Height at the culminating point of line	3772 »	3671 »	3864 »	4101 »
Length of the straight lines	46,5 miles	54,6 miles	58,5 miles	34,9 miles
Ratio of this length to the total length	0,678	0,683	0,600	0,521
Minimum radius of curves	984 feet	984 feet	984 feet	984 feet
Length of the great tunnel	9,3 miles	10,8 miles	11,6 miles	10,1 miles
Length to be done without shafts	7,1 »	7,3 »	8,0 »	8,0 »
Length to be done with shafts	2,1 »	3,5 »	3,6 »	2,1 »
Number of shafts	4	8	8	6
Maximum depth of shafts	9,93 feet	1023 feet	1023 feet	984 feet
Maximum inclination in great tunnel		one in 50	one in 87	one in 69
Length thereof	2,1 miles	2,8 miles	2,5 miles	5,1 miles
Total length of other tunnels, South side	4,0 »	1,9 »	10,2 »	14,0 »
Total length of other tunnels, North do	6,6 »	1,3 »	3,2 »	3,1 »
Total length (presumed) to be covered	2,05 »	13,7 »	26,0 »	29,0 »
Length open	48,0 »	66,3 »	38 »	38,0 »
Assumed price of the great tunnel (taking £ 173 the linear yard for the portion without shafts, and £ 180 a yard for the portion with shafts	£ 2.521,120	£ 3.045,527	£ 3.278,916	£ 3.159,632

CHAPTER XVII.

MODES OF TRACTION FOUNDED ON THE TRANSMISSION OF THE POWER BY THE ELASTICITY OF THE AIR.

§ I. — Atmospheric system properly so called.

473. We shall dwell little on this system which very lengthened applications on the largest scale, particularly that at *Dalkey*, in Ireland, then and especially that on the incline from *Le Vesinet to St Germain*, have allowed to judge of, from a thorough acquaintance with the case. But this last experiment, by the very fact of having been made under the most conclusive conditions, cannot be left completely on one side. The principle itself, if it involves drawbacks so weighty that they render it in general, pretty well impracticable, possesses remarkable properties, which deserve to be described.

Too absolute condemnations must besides, be guarded against. If the system in question has been judged beyond recall for conditions analogous to those of the applications which have been made in Ireland and France, perhaps it would be otherwise under different circumstances, particularly if the gratuitousness of the motive power allowed the radical vice of the system to be got over, that is to say the smallness of the return on account of the enormous entries of air through the longitudinal valve.

Let us in a few words bring the principle to mind.

A cast iron tube, composed of portions with very stanch joints, is laid down along the centre, the whole length of the line. It takes a piston fixed to the first vehicle of the train by a connecting bar which runs through a continuous slit in the top of the tube. A flap or continuous clack valve covers over this slit. The piston carried by a long horizontal rod, is placed in front of the connecting bar, so that the valve is lifted behind it to allow the connecting bar to pass, without being so before it. If, then, an air pump creates a vacuum in front of the piston, the latter is acted on by the difference between the atmospheric pressure and that inside the tube, maintained by the exhausting engine.

The principal elements at *St Germain* were: the given section, the load to

haul, the speed, and the corresponding resistance including the friction of the piston were such that, admitting for the reduced pressure kept up in front of the piston $\frac{2}{3}$ of an atmosphere or an effective pressure of 720 lbs on the square foot, with an internal diameter of the tube, of 2.07.

The existence of the longitudinal groove places the tube in peculiar conditions. Under the action of the interior rarefaction, it is evidently subjected along its whole periphery to a normal pressure of $\frac{1}{3}$ of an atmosphere, and at each extremity *a*, *a* (Pl. LXXXIX, *fig.* 16), to a vertical force of half the pressure on the valve. The tube may be considered as formed of two half cylinders solidly fixed horizontally at MN, and solicited by the forces indicated. These conditions evidently lead to giving an increase of thickness from *a* to M, the sum of the bending moments increasing in the same direction. To simplify the casting, this continued variation in the thickness is made up for by flanges cast on the outside near enough together to prevent any giving of the lengths of the tube between them, which is of uniform thickness.

The longitudinal valve, formed of leather strips lined with a sort of scales of sheet iron, too short to interfer with its flexibility, had for hinge a continuous rod fastened down by hook bolts, and rested on its free edge on a seating of greased leather.

The connecting bar presented a double bend α, β, to limit the rise of the valve, which fitting into the hollow thus formed in the bar, had only to incline to an angle of 45°.

This lifting of the valve which evidently could not be done by the bar itself, was prepared in front thereof by rollers of increasing diameter placed on the piston rod, which undid it from its seat, and gradually brought it up to the inclination of 45° to the right of the bar.

This fixed, the train arriving at the foot of the *Vesinet* incline, the locomotive was taken off and brought behind, it then pushed the train up to the entrance of the tube, enlarged like the end of a horn, in which the piston fixed to the van in front and held up under the frame by an articulation of the bar, was lowered and let into the tube. This piston formed alone the lower stopper of the tube; at the upper end a simple flap was brought up, and completed the isolation of the air inside. A signal gave notice to the driver of the stationary engine placed at *St Germain*; the vacuum was made. In spite of the small relative initial resistance, the incline being at first very flat, the train did not start; it was kept back by the brakes screwed down. As

soon as the required amount of rarefaction was obtained, the driver of the fixed engine gave the signal for starting; the brakes were taken off, the train started and the fixed engine kept up the velocity, drawing in at each instant the volume of air, at the internal pressure, corresponding to the velocity of the propelling piston.

As it is only a question of the application of the principle to the working of the *St Germain* incline, we shall not dwell on the arrangements, often very ingenious, thought of and tried with the view of an application to much longer inclines, upon which the division of the tube into section would have been indispensable, the useful effect rapidly decreasing when the length augments.

One of the satisfactory sides of this mode of traction, applied to a traffic of very numerous trains, would be to make the work of the stationary engines almost continuous. They work in effect not only during the running of the train, but also during the preceding period, that of the rarefaction. At *St Germain*, this period was short, because the second was also, although less. For working several successive independent sections of tube, the vacuum should be produced previously, in a tube provided in that case, with a special entry valve, worked automatically by the train leaving the preceding section.

474 *Two phases of the work.* A remarkable mechanical feature of the system is then that a portion of the motive power, corresponding to the running through of a section of tube, is stored up.

This part is produced in the interval between the passage of the trains; and the time that can be devoted to them, depends not on their velocity, but on their more or less rapid succession, that is to say their number.

The time in which the second part should be produced, that is to say the work of exhausting, depends only on the velocity; an important consideration, because it is this fraction, and not the total work, which fixes the power the engines should have.

The decomposition of the total into these two elements: rarefaction, work stored up; exhausting work, expended as fast as produced, is easy.

1st. *Rarefaction.* The tube, L in length, and S in section (Pl. LXXXIX, *fig.* 17), is full of air which at atmospheric pressure, has to be brought by the engines to the pressure p. Whatever may be the apparatus employed, we may evidently imagine the effect to be produced by placing a piston ω, at the distance $\frac{\mathrm{L}p}{14{,}70}$ from the extremity A, and bringing it, by an increasing effort of traction exerted on it, to the other extremity B.

The piston, in an intermediate position C, at the distance l from the origin A, is solicited: on its front face, by the atmospheric pressure, or 14,7 (lbs on the square inch, or 2.116 lbs on the square foot) $\times$ S; on its hind face, by a pressure:

$$2.116 \times \frac{Lp}{2.116} \times \frac{1}{l} \times S = \frac{LpS}{l};$$

the effective pressure is then

$$\left(2.116 - p\frac{L}{l}\right)S,$$

the elementary work

$$\left(2.116 - p \times \frac{L}{l}\right)Sdl,$$

and the total work

$$\int_{l=\frac{Lp}{2116}}^{l=L} \left(2.116 - p\frac{L}{l}\right)Sdl = SL\left(2.116 - p\log.\frac{2116}{p}\right) \qquad (1)$$

2nd. *Exhausting.* V ft″ being the speed of the train, the engine must withdraw per second a volume of air SV at the pressure p, that is to say that it compresses the air to pressure of 2.116 lbs on the foot, to reject it into the atmosphere. This work, equal to that which the same mass of air would restore, in expanding from the atmospheric pressure to the pressure p, is then, p SV $\log \frac{2116}{p}$; such is the theoretical work which should be produced by air pumps.

The total work of exhaustion for the length L, is thus

$$p.S,L \log \frac{2116}{p}, \qquad (2)$$

and the total work necessary to draw the train over the length L is

$$(1) + (2) = SL\,(2116 - p),$$

which is evident *a priori*, since the diameter S of the tube is determined by the condition that the force S $(2116 - p)$ be equal to the sum of the resistances of every nature which act on the train.

Different contrivances have been proposed for suppressing the longitudinal valve, but have had no success. It is useless to dwell on them.

It was thought to substitute compression behind the piston for rarefaction in front. The effective pressure could be thus pushed much higher, and the diameter of the tube reduced by so much; but the closing of the tube offered insurmountable difficulties.

The experiment of *St Germain*, which according to the conditions of the subvention of £ 72.000 accorded by the government, was to commence at *Nanterre*, and thus include a long piece of horizontal, came after the leng-

thened application made in England; from *Kingstown* to *Dalkey*, Ireland (1,86 miles); then from *Sydenham* to *Croydon* (4 miles) where the locomotive resumed its place in 1848; from *Exeter* to *Dawlish* (8 miles). To recommence, on a level, a trial which could lead to nothing new, would have been perfectly inconsistent.

The application to a gradient of unusual inclination at that period, one in 28,6, was on the contrary justifiable on plausible grounds; and perhaps use may be made some day, for some difficult passage in a mountainous country, of the results obtained at *St Germain*; although speaking truly, the employment of the rope with reduced section and increased speed is much more economical, even in the case where abstraction could be made of the cost of the motive power.

§ II. — **Pneumatic atmospheric system, or with enveloping tube.**

475. They had succeeded on the *St Germain* line, in considerably reducing certain disadvantages of the system, such as the expense and constant difficulty which the greasing of the propelling piston involved, and which was afterwards found to be useless.

But the main evil, the enormous leakage by the longitudinal valve, remained, in spite of all efforts.

There is a radical means of suppressing the drawbacks of the longitudinal valve, and that is, to suppress the valve itself; but for that the tube must be enlarged to the point of being able to take not merely a small piston but the train itself acting as a piston. A low effective pressure is then sufficient, on account of the great surface acted on.

Admitting, as has been stated, that in regard to the useful effect of the motor, this system leaves the preceding one far behind, the enormous expense of the tube, seems at first sight, a veritable impossibility; and if a reduction of expense be admitted by reducing the section, practicable only in that case for a miniature rolling-stock, the affair would only end in a botch, without any value, with regard to a great line of traffic.

The first idea is attributed generally to *Medhurst* a Danish engineer, who is said to have broached it in 1810. But according to M. *Ghega* (*), it belongs to *Taylor* of *Manchester*, who proposed it in 1805, as applicable to the transport of letters; and *Medhurst* thus only reproduced it five years after-

(*) *Quadro dei progressi delle strade ferrate. Vienna*, 1852, page 5.

wards, in extending its application. It was taken up again towards 1820 by an English engineer *Vallance*, who proposed to connect *London* with *Brighton* by a tube in cast iron, of large section, in which the air was to be rarefied in front of the train. Some summary trials not succeeding, the idea was given up, to be resumed, after being long forgotten, on the one part by M. *Edwards*, who submitted it to the technical commission charged by the Italian government with the examination of the different modes of traction applicable to steep gradients, and on the other by M. *Berrens* (*), then by M. *Daigremont* (**), both French engineers, attached to the Central Italian railways.

According to the project of M. *Edwards*, which was not very fully worked out however, the tube is to be in masonry. The piston waggon, placed behind, drove the train, under the action of the air, compressed by means of a fan analogous to an *Archimedes* screw. An effective pressure of $\frac{1}{10}$ atmosphere was sufficient for a train of 100 tons on a gradient of one in 10. The safety brake was composed of two blocks, pressed more or less strongly against the sides of the gallery.

The proposals of M. *Berrens*, and those especially of M. *Daigremont*, are more complete.

M. *Berrens* adopted exclusively the metallic tube; the enormous expense led him to adopt a reduced diameter, from 9,35 to 9 ft, 84, instead of 14 ft, 66, as would be required by ordinary stock. He thus reduced the expense by one half, but involving double transhipment.

In taking up the principle, M. *Daigremont* rejects transshipment, and carries consequently the diameter, finished, to 15 feet; the section of 162 square feet gives, with an effective pressure of $\frac{1}{10}$ of an atmosphere, a tractive effort of 17 tons sufficient for a train of 200 tons on a gradient of one in 12,5.

M. *Daigremont* insists on what he calls an impossibility in M. *Berrens's* solution.

The tube in plate iron could not remain, says he, uncovered throughout. It would be necessary to protect it against the fall of blocks of stone, and against avalanches. It would require on all the threatened points, an envelope in masonry, so that instead of being almost completely free from the necessity of costly works other than the tube itself, the system would on the contrary be subjected thereto in a high degree.

(*) *Traversée des montagnes avec l'air comprimé dans des tunnels métalliques. Milan*, 1861.
(**) *Étude sur le chemin de fer atmosphérique. Turin*, 1865.

"In that case", says M. *Daigremont*, "is it not better to suppress the metallic envelope, and run the trains in a simple tube of masonry, that is to say, an ordinary tunnel?"

To which the late M. *Berrens* would have no doubt replied, that where the envelope in masonry was required, the metal lining would disappear; that the system would be compound, sometimes metal, sometimes masonry, according to the local conditions, but never the two together.

The two engineers were no more agreed, as to the details of the mode of propulsion. M. *Daigremont* proceeds by rarefaction, against which M. *Berrens* brings forward two objections: on the one part, the necessity (or nearly so) of placing the motors at the upper part of the passes to be got over, that is to say under condition generally little favourable for the collection of water for motive purposes; on the other, the greater rigidity required to be given to tubes pressed from the outside inwards.

The first objection is valid; the second is so also for the metallic tubes which M. *Berrens* had alone in view; but the tubes in masonry would suit much better on the contrary for an external than for an internal pressure.

476. The system with envelopping tube, whatever may be the details of construction, has certainly something taking at first sight. It eliminates all complication of machinery; it suppresses the leakages of the longitudinal valve; it greatly reduces those of the piston, on account of the more favourable ratio between the section and the perimeter. To the enormous expense of the tube, its partisans oppose the reduction of length due to the inclination of the gradients, carried at need to one in 10. M. *Berrens* invokes, in favour of his metallic tube, the simplicity of the works proper, the tube itself being already a hollow girder of greater rigidity. Lastly, it is claimed for the system, (without laying too much stress thereon, and with grounds, as regards the question of price), two advantages deemed incontestable: simplicity and safety.

On this later point, safety, it is necessary to know what is meant.

It will be readily agreed that there is nothing to compromise passengers as to lives in the system; but as to what concerns the safety and continuity of the communications, there may be more doubt. A slight subsidence, a small disturbance of the cross section or of the longitudinal axis, would not prevent the passage of the piston, but a more serious alteration in the cross section would involve, if not a regular accident (the breakage of the piston made purposely light might bring such about), at least a lengthened interruption in the running. It is not in this case a question only, as in the ordinary system, of clearing the line and keeping it

free, it must also be kept stanch, which is the condition of action of the motor; and this tunnel placed on the surface, would evidently be more vulnerable than the real tunnel running within the depths of the ground.

As to the useful effect, satisfactory perhaps, as long as the velocity were very low, and the tube very short, it would certainly be very indifferent, if the velocity were carried to twenty five miles an hour, and the length to a few miles. If, looking on the system as a solution of traction on steep gradients, its application be restricted to that case, of course the velocity need not be considered; but it would always be necessary to have the velocity high enough, for a single tube, under slight pressure, and on steep gradients to be sufficient for a considerable traffic. In whatever manner the action may be produced, by rarefaction or by compression, there sets up in the tube, by the fact of the movement, a pressure decreasing throughout its whole length, in the direction of the running of the train, and which has the atmospheric pressure for upper limit in the one case, and for lower limit in the other.

The depression which the engines have to keep up, is the difference between the pressures at the two ends of the tube while the motive or useful pressure is only the abrupt fall between one face and the other of the propelling piston; a fall always small relatively to the total depression, as long as the velocity is not very slight, and the tube has a certain length. It will thus be understood that the useful effect, variable besides with these elements, would be always very small.

If, in certain applications, in the works of the great Mount Cenis tunnel, for example, compressed air has shown itself a faithful depository of power transmitted to great distances, the observations, not complete by the way, made in the circumstances in question are not directly applicable to the case before us. One cannot help, on this subject, regretting that before handing over this gigantic tube of 7 ½ miles to its destined purposes it had not been made use of, with all its mechanical appliances for experiments on a large scale on the flow of gases.

The contrivances proposed for reducing the leakage round the piston have not yet been made the object of any experiment.

A complaint, of secondary importance however, is the scarcely agreeable position of the passengers, compelled to pass in a close dark vessel, precisely through the middle of the finest aspects of nature; but with railways, it is always so; whether it be a question of a tunnel buried 5.000 or 6.000 ft, as in the Alps, or of a tube on the surface, the situation in this respect is the same; and the modes of traction which require neither the close

vessel, nor the limited altitude in no way escape as we have seen from the same condition; the pneumatic system has at least, essentially, the advantage of assured ventilation.

The main objection, that before which all others vanish, (unless it be however the danger of lengthened interceptions on account of deformations in the tube), is the cost. In principle, its value depends, as we have already said, on the importance of the traffic. It would be necessary, before all, to know for what traffic one line, that is to say one single tube, would suffice. On this point, as on so many others, there can be nothing but simple conjecture, the brief of the pneumatic system containing only at present simple hints.

It escapes, by that very fact, from criticisms, which would be much more precise, and perhaps more decisive were it better known.

477. To accept long tunnels in order to limit the altitude, is all right enough. But to accept a continued indefinite tunnel, so to say, *as direct and necessary consequence of the mode of traction*, is according to us utopian, whatever may be too, the construction preferred : metallic tube, or masonry. Without doubt, in order to get rid of a great tunnel properly so called, the necessity must of course be accepted of covering the line over for a great extent, and in this respect, the pneumatic system, to a certain point kills two birds with one stone; but the cost of the construction and maintenance of a simple gallery for protecting the line from the snow, and of course excepting at those points where it has to resist avalanches, is quite another thing from that of a tube, whether in metal or in masonry, perfectly stanch, and obliged to be absolutely indeformable.

As long as a question is in that predicament, so long the discussion can only be made on hypothetical elements, and there is no use in dwelling on it. All that can be conceded is that the pneumatic system is not impossible. We may admit besides, without difficulty, that in the case where a tunnel arises naturally out of the very conditions of the trace, pneumatic propulsion may in certain cases be balanced against the other mode of traction, and that the section may even be modified in consequence, by augmenting the inclination by a great deal.

The tunnel so little adapted for the locomotive, even with moderate gradients, is on the contrary suitable for pneumatic traction, even with very steep gradients, provided the length be small.

478. There is already a question of applying this principle, going to

the limit, that is to say a tunnel inclined at an angle of 90°. M. *Blanchet*, director of the *Epinac* mine, has investigated the application of compressed air to a mining shaft the depth of which would be 2.300 feet; the system of buckets representing in this case, the train and its piston. But the necessity of working to several levels complicates the problem.

The carrying out of this project would be of great interest not only for mines, but for railways also.

The applications of the principle are confined at present to the little tubes established in *London*, then in *Paris* and *Berlin*, for the carriage of letters; and a specimen of a passenger tube, formed as some years ago, part of the curiosities of the Crystal Palace.

The success of the trials made in *London*, by the *Pneumatic Despatch* Company, led the French authorities to substitute in part, in the interior of *Paris*, a system of pneumatic channels for telegraph wires. The material transport of despatches thus replaces their transmission by telegraph, which is very difficult over a network with the meshes so close.

It would have also, if desired, the advantage of maintaining like the ordinary post, the secrecy of the despatches.

The tubes, only 2 ins, 5 in diameter receive the little carriages bearing the despatches inclosed in copper cylinders. The little train, terminated by a piston with a cupped leather, is driven by compressed air at a speed of 1.640 feet a minute. The reservoirs of compressed air are supplied by the water brought by a small branch from the water companies' conduits.

At *Sydenham*, the gallery in brickwork, 9 ft, 84 high and 9 feet broad, took the passenger carriages of the Great Western. A fan 20 feet in diameter, maintained an effective pressure of $\frac{1}{96}$ of an atmosphere, which was sufficient by reason of the small load.

§ III. — **Propulsion by the direct action of water on the train.**

479. *System of propulsion of the late M. Girard.* The utilisation of natural falls, or more generally of water stored up in reservoirs, is the basis of many an engineer's program in his studies of the crossing of mountains by railways.

The work of the water may be transmitted to the train, either by cable with direct traction, or by the high speed cable of M. *Agudio*, or by the elasticity of the air.

In M. *Girard's* system, all intermedium disappears; the water itself acts directly on the train, which represents both, hydraulic receptor and the resistances. The natural conditions would rarely be adapted to the application of this mode of propulsion, which would require sufficient resources in motive water, from the bottom to the top of the gradients to be overcome. Besides M. *Girard* did not occupy himself specially with the question of gradients. He claimed the creation of a system of propulsion sufficient in itself, and capable of supplanting the locomotive, not only in the circumstances where its advantages become nought, and its disadvantages excessive, but everywhere and altogether. This was to take attention off from what was really applicable in the principle. Instead of attacking locomotives on the ground where they are inattackable, that is to say on moderate gradients, it should have been proposed to replace them only where they become impotent, that is to say on steep gradients; the more so as then only the smallness of the speed possible, whatever may be the mode of traction, greatly reduces the weight of the objections which the hydraulic system gives rise to.

The system is founded on the establishment of reservoirs under pressure, at distances, and of a propelling tube placed along the axis of the line, provided with valves, which the train would open and shut itself. Such effects can only be produced slowly; at a high speed the automatic action would produce inadmissible shocks, and the flowing out of the water not taking place with the theoretical velocity, there would be much time lost.

If each nozzle is opened as soon as the head of the train reaches it, and closed as soon as the end of the train passes it, the jet acts without loss on a series of cylindrical floats on vertical axes, suspended to the axles under the frames of the vehicles.

Generalising the application of his system and admitting then the necessity of an effort of traction developable in both directions, M. *Girard* was led to duplicate the nozzles and the floats, forming two systems directed in contrary ways. The two series of floats had thus to be superposed and thus the corresponding nozzles placed at different heights.

As to the details, it will be remarked that, admitting the possibility of the application of the system to steep gradients, it would end, like many others, in constituting for these particular points, special rolling stock unless the running throughout of the vehicles with their floats were put up with.

It has been proposed by an English engineer to apply running waters directly to drawing train on inclines. The water and the train running in

contrary directions, the first flowing along a trough into which would be let the flat floats keyed on to the middle of each of the axles, which thus become regular driving wheels. This is nothing more than an application of hanging wheels, approximating to undershot wheels with flat floats, in so far as the channel forms a sort of run enclosing the floats.

480. *Sliding railway.* — The project presented by M. *Girard* in 1852, was reproduced by him some ten years later, with an addition which caused it to receive the name of *sliding railway.* The mode of propulsion is that which we have briefly indicated; the modification consists in the suppression of wheels, axles, and the large suspension springs of vehicles.

The frames rest on rails greatly widened (10 ins, 34) by the intermedium of simple skids in cast iron, with the interposition of small springs. The vehicle is thus changed into a sledge, which is only admissible by the condition of enormously reducing the friction: a result obtained by M. *Girard* by completely isolating from each other both skid and rail by a small layer of water forced in between them.

The tube which brings the water to each skid ends at its centre, and the water is distributed over its whole surface by grooves. The skid is raised a little and slides thus, not on the rail but on the water.

The train carries a reservoir maintained under pressure, either by taking from the forced conduct laid underneath the line, or by a steam engine taking the water from a tank installed like the engine itself on a special sledge, and which would be supplied by a process analogous to that applied by M. *Ramsbottom* to tenders (322).

The experiment made at *la Jonchère* was very interesting; it made evident the considerable effect of water under pressure in greatly reducing the friction. The idea can be applied to bearings, and in effect, has been so. It is an ingenious way of carrying out lubrication by water (76). But what is very easy when it is only a question of a bearing, is absolutely impracticable for the whole extent of a railway. The considerable breadth to be given in this case to the sliding surface of the rails, the expenditure of water necessary to keep the surfaces apart, are only secondary objections. What would be impossible, is to give that sliding surface the absolutely regularity and invariability it imperatively requires. The least subsidence, the least deformation of the surface, would every moment disturb the effects. The skids would come upon the rails bringing in, inopportunely, enormous resistances, those which should only come in as a brake, when the access of the water under the skids was stopped purposely.

It would be necessary, for the regular action of the system, that the line should be established under the same conditions as the foundations of a regular piece of machinery. Here again, we have an ingenious idea, remarkably strained in the endeavours to apply it.

To sum up, as long as we can, without exaggerated sacrifices and without too sharp curves, about 220 yards, limit long inclines to about one in 40, there is nothing more required than the ordinary locomotive, that is to say, acting by the intermedium of the adhesion due to its weight. But if a notable excess beyond these limits cannot be avoided, even with respect to one only of them, or if they cannot be kept within excepting at too great a cost, the application of stationary engines with rope must be taken up resolutely and without distrust, introducing therein the improvements due to M. *Agudio*, and without hesitating to push the inclination to one in 5, and even beyond that, the limit resulting only then from the consideration of safety alone.

As to the other solutions proposed, or even tried, the ones, such as the pneumatic system, seem to us, as far as a general solution, and save with the exception just now made (475) to belong particularly to the realms of fancy; the others, like the locomotives and rack, are unless perhaps in the shape of purely temporary applications rather mechanical curiosities than serious instruments of traffic.

The locomotive is a marvellous implement, but we should know when to relinquish it, that is to say when the conditions of the work to be done are in opposition to its nature.

For us, continuing our task, we return to the locomotive, to study it as a motor, as a steam-engine.

NOTES AND ADDITIONS

No. **40** (page 46).

In this number regret was expressed that the carriages with two stories could not be applied to the service of the *Vincennes* line, on account of the insufficience of its loading gauge. M. *Vidard* remarked, with reason, in 1870, that this insufficience only affected the lower portion of the gauge, on account of the raising of the platforms which did not allow the doors of the carriages with two stories to open, from the lowness of the bodies. The substitution of low platforms for those of 3 ft, 30, given up almost every where, was carried out at the end of 1870; and thus removed the only obstacle to the running of the carriages in question. Notwithstanding this, the carriages with seats on the roof, of the special *Vincennes* type, are still alone in use on that line.

No. **75** (page 86).

Lubrication of carriages and waggons by oil.

Since the publication of the first part of the French edition of this volume in 1870, the *Méditerranée* company took the step of substituting oil for grease for the journals of their carrying-stock. The altered boxes belong to the type cited in the text, with two reservoirs, the one below for oil, the upper one for grease, kept to fall back on.

The substitution in question is an important, delicate operation, the success of which depends on the care with which very minute directions are carried out. The most of the lines which have hitherto continued to use grease, will be certain sooner or later to come to oil, and to take for guides, to a certain extent, those preceding them in the matter. It is thus of use to reproduce the directions given by the *Méditerranée*.

1st *Order*, *No.* 144.

20th Dec. 1871.

" It has been decided to give up lubrication by grease of the axles of the carriages and waggons actually in use, to replace it by oil (with the exception of ballast waggons V, V*f*, and VH*f*).

" The alteration of the axles now being made and the suppression of the boxes which do not allow of the use of oil, will have for result, when these operations are completed, the suppression of the old types of axles and boxes, and the keeping of only three types of each kind, namely:

" *The axle type* 2 (Pl. XII, *fig.* 59), *running with box* G — 2 — H, this latter is proposed).

" *The axles types* 7 *and* 8 (*figs.* 64 and 65) *running with the boxes* G — 8 — H, *and* G — 8 — H, 1870.

" All the vehicles placed on the axle types, 2, 7 and 8, with boxes G — 2 — H, or G — 8 — H, and running with grease, which come back into the shops shall receive the necessary modifications for running with oil.

" These modifications will not be applied to the vehicles on axles and boxes of the other series which are to be withdrawn.

" They will be applied first to low speed (petite vitesse) waggons, and later to the carriages and *high speed waggons.*

" These modifications or preliminary operations, for passing from lubrication by grease to that by oil, are described summarily as follows:

" The boxes will be taken down and washed with potash.

" The openings in the grease box will be stopped up with hard soap, poured in hot.

" The reservoir will be filled with grease made specially for the purpose, and which will be termed *Grease for oil boxes* (grey color).

" The lid of the box will be closed by screws. A greasing pad will be placed in the bottom of the box or oil reservoir.

" The joint between the top and bottom of the box will be made with a piece of leather stamped out, or a lead wire, comformably with the following instructions:

" The box will be closed, on the side next the nave, by an oval washer, either in sized linen or compressed hemp, passed on to the axle, and let in to the grooves arranged to take it, in the two halves of the box.

" Lastly the bottom of the box will be filled with oil, which will be introduced through the orifice made for the purpose therein.

" The proper action of an oil-box depends on the thorough carrying out of the arrangements just explained. I thus think well to give precisely, the pre-

cautions to be taken for that purpose, and this will be the object of Nos. 1 to 8 following. These clauses will point out the general measures to be taken for the working and maintenance of oil boxes.

" 1st. The new box must be cleaned off from the casting sand which is often found sticking to its sides : the openings will be especially examined, as well as the upper grease reservoir and the bottom of the box.

" The screwed cap of the upper part must be seen to close thoroughly, and there must be no crack through which the oil can escape.

" 2nd. The brass ought to fit well in the box; it will be adjusted on the journal with extreme care in the cylindrical portion so as to arrive at the maximum of rubbing surface.

" The file will be passed over the lower edge of each side of the brass, so that it may not act on the oiled journal below as a scraper; but this edge must not be taken down as a regular arris which would reduce the bearing of the brass, and cut into the channels.

" The normal brass is shorter than the journal, which means that end play is wanted. Experience proves that a box lubricated by oil, when it heats, cannot come right of itself, that is to say cool like a grease-box; exceptional perfection is thus necessary in the adjustment of the brass at the outset; this is the most important point with oil-boxes.

" 3rd. The openings which let down the grease from the upper reservoir to the brass ought to be stopped up, seeing that the grease ought only to come in the case of regular heating. These openings are stopped with a sort of hard soap, proceeding in the following manner:

" The brass is taken off, and the body of the box placed in its normal position, on a piece of wood of the same shape as the outside of the box, and which is fitted with pieces of stuff or leather for closing the underneath of the openings. The soap is melted in a can with a neck, then it is poured through the grease reservoir in such a manner as to partly cover the bottom. This excess of material necessary for facilitating the operation and obtaining plugs sticking well to the cast iron, is removed after it has cooled, by a spatula. The stoppers thus made are only in contact with the box, the openings and the channels of the bearing being exempt therefrom, a necessary condition for avoiding the partial melting of the plugs and so only allowing the grease to come in at the required moment.

" 4th. After having stopped the openings in the manner just described, the reservoir is filled with *Grey grease for oil boxes*, as completely as possible, by the ordinary means; the cover is then closed, and the plug screwed up.

" The grey grease employed for this use is harder than that used in the current service, even than summer grease, for it ought only to come into use when the heating of the box is decided. It will be prepared exclusively for this purpose. It will not be given to the regular greasers, but only to those men charged with

the fitting up of the oil boxes, or with replacing the oil in boxes which have accidentally run with grease.

" To distinguish it from others, the oil-box grease will be coloured iron-grey, and the Store department will deliver it in casks or barrels the bottoms of which will be painted of the same colour.

" The oil-boxes which on account of heating, may run accidentally with grease (see No 10) will be supplied with ordinary grease suitable to the season.

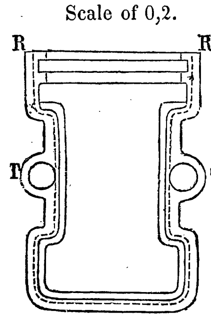
" 5th. The pad ought to take the oil from the bottom of the box, and oil the journal underneath. It is formed of a wooden carcass fitted above with fluffy cotton webbing, and below with eight plaited wicks and four wicks not plaited coming from the upper webbing and going right down into the oil of the reservoir. This pad is guided in its up and down movement by the bottom of the box. It carries at each end two projecting pieces of wood the object of which is to keep it parallel to the journal and prevent an undue pressure on the pad; one or two spiral springs keep the pad against the journal.

" The wicks will be properly arranged from above downwards without being entangled; the pad must rise and fall, when in place, with facility, and no wick must be between the pad and the cast-iron.

" There are two patterns of these pads: No 1 is applied to the old G — 8 — H, boxes and to the boxes G — 8 — H, 1870; No. 2 is applied to the G — 8 — H, 1870 boxes, and will probably be to the G — 2 — H boxes; it is better guided and will become definitive for boxes of that pattern. The number of the pad is stamped hot on the wood of each one.

" 6th. The joint of the box with the upper part ought to prevent the introduction of dust into the box, and also the entrance of water which might run along the lugs and thus reach the bottom containing the oil. To this effect, there will be placed in the return angle of the surface of the joint of the upper part of the box, a lead wire following its sinuosities as shown in the accompanying sketch: the wire is marked by a dotted line. This wire leaves outside the hole T of the lug and runs to R where it is bent over into a little notch made by the file. The lower portion is fitted into the upper and the lug-bolts are tightened up which draw the two halves of the box together with force enough to crush the lead wire down to one half. In order that this joint may not give, the forked lug must go right down home into its place when the lug is forked, and further that the double nuts be pinned exactly, which can always be done with additional washers.

Scale of 0,2.



" The lead joint is the only one practicable for the oil boxes G — 8 — H of the first manufacture, in which the surface of the joint is very narrow, and carries no return on the side of the upper portion of the box.

" The lead wire is one eighth of an inch in diameter.

" Since, a second pattern has been cast with more joint surface and outside edge to the upper portion; lastly, a third pattern : G — 8 — H, 1870, in which the joint at the upper portion of the box is broader also and has an edge both outside and inside. For these two boxes, the joint is easier to make with a greased leather stamped out to the shape of the joint. This leather is applied on to the edge of the lower portion of the box before putting it in its place; often with boxes G – 8 — H, 1870, it is easy to get the leather to hold on between the two edges of the upper portion of the box, and thus there is one thing less to do at the moment of putting on the bottom portion.

" 7th. The leathers for the joints will be prepared at *Paris*. Their thickness may vary from 0.12 to 0.20 of an inch; below 0.12 of an inch they would be wanting in the elasticity necessary to make up for the unevenness of the cast-iron which is neither dressed nor planed.

" The lead wires and the leathers will be delivered by the Store.

" To prevent dust getting in on the side next the nave, there is placed on the turned down portion of the axle next to the journal, a washer of sized linen or compressed hemp, of oval shape, with a hole to allow the axle to pass through; this washer is placed on the axle before the box is put in place and it becomes fastened in by the upper and lower portions of the box joined together. The dimensions of the washer and of the grooves are made with reference to the displacement arising from the wear of the bearings. The axle turns in the washer fixed immovably in the box; the thickness of the washer is adjusted so as to fill up the space left in the box; in fitting the boxes care must be taken that it really occupies its assigned position, and gets out neither on one side nor the other.

" It is necessary to employ with oil-boxes only the axles of the last pattern, without projecting keys and without any groove on the keying on portion. Every axle type 2, 7 or 8, not having had the groove turned down, must be sent into the shops to have that done.

" 8th. The oil boxes G—8—H. and G—8—H. 1870, have their lower portion of such a shape that it cannot be put on without being reversed.

" To avoid losses of oil and in order not to dirty the pads by sand or by the dust which covers the ground in the shops and stations, we shall supply the lifters with a box of tools of such a shape that they can place therein one over the other the two lower portions of boxes, and keep sheltered the etceteras such as washed pads and so on, which pieces must on no pretext be placed on the ground.

" 9th. When an oil-box is fitted on for the first time or when the pad is changed in a box already running with oil, oil ought to be poured on the pad, it should then be put into its place and pushed down by the hand several times to make the wicks take up well. The box is closed with care, seeing that each part, such as : bearings, washers, pads, etc., is all right in its place. Then the sup-

plement of oil is added, pouring it in through the spout on the upper portion of the box.

"The level of the oil is regulated at 0,87 of an inch below the mouth; under these conditions, it will work all right. Any more oil that might be added would be lost in the oscillations of running, and would thus increase in a very great proportion, the useless expenditure of oil. The lifters should never lose sight of this important condition of economy.

"10th. When a box heats, the greaser will undo the screw which keeps down the lid, and will fill it with ordinary grease, and will attach on to the frame of the waggon *above the box*, a red ticket form no. 2331 bearing the following inscription: *running with grease, to be raised when emptied,* and will take care to fill up the counter-foil.

"11th. The screws taken off from the boxes in the case of heating will be handed over by the greasers to their foreman, and forwarded on to the carriage and waggon superintendent at *Paris.*

"12th. In the stations where trains are formed, the greasers will inspect the boxes. They will open the lids and will fill the boxes with oil if required, to the regulation level of 0,87 of an inch below the mouth, and will make sure that the boxes are not damaged, and are not allowing oil to pass through the joints. During long stays in stations, a similar inspection will be made, and will apply principally to the waggons added on the road at the small intermediate stations, these waggons not being able to be examined when attached to the train. For this purpose the greasers of those stations where waggons stand for long periods will be supplied with oil cans.

"13th. In the stations where no long stays are made the greasers will not interfere with the oil-boxes unless in the case of heating (see No. 10).

"The greasers of these stations will be supplied only with grease and not with oil.

"The distribution between the inspection on departure, and that on the journey has for object to arrive in application at attending to the level of the oil only at long intervals. An oil-box in order can run several months, and it would be simply wasting time and wearing the lids and springs uselessly, to go opening and shutting the lids at each station as is done for grease boxes. From this point of view, lubrication by oil possesses an advantage which should be profited by.

"14th. All boxes which have heated whether running with grease or not must be compulsorily lifted and replaced with oil-boxes. The vehicles, after unloading, will be consigned to the nearest repairing or running shed. The boxes will be washed with potash and put completely in order.

"The boxes, which have been regularly running with oil should be as much as possible, inspected by lifting, after a length of service varying according to the series of waggons, namely :

" 1 month for post-office vehicles.

" 1 $\frac{1}{2}$ month for 1st class and express luggage vans.

" 3 months for 2nd and 3rd classes, composites and 4 wheeled luggage-vans, horse boxes and carriage trucks.

" 6 months for all goods-waggons.

" These liftings will be verified by ordinary stamps.

" The inspection has for object to discover what bearings require to be touched up, especially for carriages running at high speeds.

" When the axles and the bearings can be kept in service, it will be desirable to mark them so as to replace the same bearings on the same journals.

" The oiling pads will be changed when they are found hardened and choked up by detritus; they will be retained when they are found to be still thoroughly capable of taking up oil.

" The oil found in the bottoms of the boxes is ordinarily thickened by detritus of every sort. This oil will be emptied into special cans; and the bottom of the box having been well cleaned, it will be filled with fresh oil.

" 15th. The oil withdrawn from the boxes will be collected in order to be used again after decanting. This operation will be done by the shops where the old oil is collected and according to instructions we shall give hereafter when we shall have studied practically the most suitable process of purification : in the mean time each shop will do the decanting in the best way possible.

" 16th. The pads, washer, leathers, and lead wires for joints, tool boxes, etc., will be requisitioned on the Store. The pads and washers will be examined with extreme care at the time they are received, and the men who have to make use of them should further, before placing them in the boxes make sure that these pieces fulfil the conditions necessary to good service.

" 17th. New vehicles will be lubricated by grease when they leave the manufactory. They will thus do the distance from the manufacturer's shops to that of the company charged to receive them. There they will be altered for oil before going out for service. In this way, the faults of fitting can be ascertained, which it is so important to rectify, before commencing lubrication by oil.

" The entry of the fitting up of oil will be made in the register form No. 2332, as stated in No. 19.

" 18th. The waggons the axles of which have been altered in the shops, and which by that fact have been fitted with oil boxes, will be lubricated by oil in the shops before entering on service.

" 19th. The shops and running sheds will take the numbers of all the waggons they have fitted for oil for the first time, with the date of the operation, and will transmit the list to the chief superintendent at *Paris* month by month as form 2,332 A.

" This entry will include all waggons fitted for oil, whether taken from running, from the manufacturers, or whether they have had their axles altered.

" 20th. When oil-boxes are lifted, care will be taken to find out every peculiarity affecting their working. The heads of shops and running foremen will follow these operations as often as possible so as to be able to recognise the points requiring any rectification. These observations will be entered in a register form No. 2334, and will bear principally on the state and the quantity of oil in the reservoirs, on the state of the journal, and the regularity of the lubrication, on the holding of the joints. The engineers of the shops will abstract these documents and transmit them to the chief engineer, every month, on the printed form No. 2335, in order to enable him to effect all possible improvements.

" 21st. It is indispensable to know the number of times oil boxes have heated, and required the temporary use of grease in those boxes. To this effect, every time a waggon running temporarily with grease is returned to oil, the head of the shop where that operation is effected will enter, on a list, form No. 2333, the date of the operation, the number and letter of the series of the waggon, the number of boxes which have heated. He will indicate, in the column of observations, the facts come within his knowledge, whether as to the causes of the heating, or the effects produced.

" The inscription in the above case ought to be carefully distinguished from that provided for by No. 19, for waggons fitted for oil the first time.

" 22nd. The alteration of the service of the lubrication will occasion expenses, which will be classed under three different heads:

" Installation of lubrication with oil (order to open);

" Current expenditure on oil lubrication;

" Current expenditure on greasing.

" In the account: installation of lubrication with oil will be included: the expenses, labour, and materials connected with the following operations:

" Lifting the waggons, taking down, potashing, and refitting the boxes, adjusting the brasses, supplying:

" Pads, lead or leather joints, washers in canvass or hemp.

" The modification of the boxes in cast iron and of the bottom portion is required either by the alteration of the axles, or by the alteration of the lubrication. It would be impossible and indeed without utility to make the distinction for each case; consequently all the expenses relative to the changing of the boxes, will be carried to a special column for the order of the alteration of the axles. We can easily appreciate, when the operations are completed the portion of the cost which has to be borne by each.

" As far as regards the brass bearings, the adoption of oil lubrication will cause no change in the patterns; they should continue in service or be replaced at the cost of maintenance.

" For the boxes in service running either with oil or with grease, the expenses of maintenance of the boxes and brasses will continue to be placed under hea-

ding XI, §§ 4 and 5, General Accounts: *Axles fitted, grease or oil-boxes*, or *axles fitted brasses.*

" The other maintenance expenses will be carried to heading XII, § 10, *Greasing carriages and waggons* (staff included); three subdivisions only will be made, as follows.

" In the first subdivision: *Lubrication by oil,* will be brought:

" The cost of fusible plugs, grey grease and oil, either for installation, or current service, and the expenses of the maintenance and the renewal of greasing pads, joints in leather and lead, washers in canvass and in hemp.

" In the second subdivision: *Lubrication by grease,* will be entered ordinary grease, the oil employed for clearing out the boxes in winter.

" In the third subdivision: *Staff,* will be entered the expenses relative to the staff of greasers for both grease and oil indiscriminately.

" 23d. The installation of oil lubrication will be done at the rate of a huudred (100) waggons per day from the 1st. Jan. 1872, which corresponds to 30.000 waggons a year. According to what has been said previously, the waggons to be changed for oil are from three sources:

" 1. The waggons taken from running which are already running on boxes G—8—H.;

" 2. New waggons coming from the manufacturers;

" 3. The waggons on oil-boxes in the shops after the alteration of the axle. "

2. *Instruction, No.* 145 *for examiners and greasers.*

20th Dec. 1874.

" 1st. They will commence, the 1st. Jan. 1872 to run waggons lubricated with oil; the trains will thus include ere long waggons with grease-boxes, and waggons with oil-boxes. The number of these latter will go on increasing until the complete disappearance of the boxes arranged for grease.

" 2nd. The boxes running with oil are furnished like the others with an upper reservoir for grease with its lid; but this lid is kept closed by a screw which can only be opened by a key. The oil is placed in the lower portion of the box; this lower portion carries a mouth closed by a small movable lid, which allows the level of the oil to be noted, and more to be added when necessary.

" 3d. The box is filled by pouring the oil in through the mouth of the lower portion of the box. The level of the oil will be kept at 0,87 of an inch below the mouth; under these conditions the service is certain. All added beyond this would be lost in the oscillations during running, and would uselessly increase the expenditure of oil in a very great proportion. The examiners, lifters and others

engaged in the greasing should not lose sight of this important condition of economy.

" 4th. Reproduction of No. 10 of the preceding instructions.

" 5th. Reproduction of No. 11 of the preceding instructions.

" 6th. The service of these boxes in the stations and in the trains will be done as heretofore, filling the boxes which are more or less empty with the grease of the season.

" 7th. The service of the boxes running with oil includes two operations quite distinct from the point of view of the examiners and greasers; the inspection at departure and in the large stations, the inspection at the passage of the intermediate stations.

" 8th. No. 12 of the preceding instructions.

" 9th. No. 13 of the preceding instructions.

" 10th. In the stations where there is a small running shed, the examiners whose duty is to insure the proper state of the stock should take a note of the state of the oil-boxes of the waggons which pass through these stations, and supply the reservoirs with the necessary oil.

" The trains will thus be formed with waggons reputed in good running order. The inspection that will be made at the departure, by the examiners or greasers has for object to give a further guarantee and to repair any omissions which might have been made on the waggons in the station. "

3. *Instruction No.* 146. *Appendix to instructions Nos.* 144 *and* 145 (20*th December*, 1871).

6th April 1872.

" Since the oil boxes have been run with, some irregularities have arisen, to which I think necessary to call attention.

" A pretty large number of oil boxes are running without the screw which closes the lid, although these boxes have not heated nor the waggons received the red ticket indicating heating. The screws have been removed, either on our system, contrary to orders, or on foreign lines. These boxes being without the screw, are plied with grease without requiring any; other boxes are now running with grease, without the ticket.

" Certain stations, believing that the red ticket from No 2331 does not necessarily involve the alteration of the waggons carrying them, continue the service of these waggons with grease.

" Lastly, the lower portions of the boxes G — 8 — H, old pattern have too small a capacity and the boxes want oil.

" In order to remedy these various drawbacks, I request all those employed

in the locomotive and carriage departments to attend to the following instructions:

1st. It is formally prohibited to the greasers or examiners to remove the screws from the oil-boxes, excepting in the case of heating, as indicated in No 4 of instruction 145.

2nd. On placing or replacing the screws, they should be only pressed on to the end of the turns, avoiding with the greatest care too much tightening, completely useless, and which may cause breakage.

3rd. The upper lid of the oil boxes will be painted white, in order to allow them to be distinguished at first sight, whether running with oil they have lost their screw, or whether running with grease they are without the ticket from No. 2331.

4th. When a box having lost its screw accidentally, and has not got the red ticket from 2331; if moreover the box shows no sign of heating and if the upper reservoir is full of grey grease, in this case, the box should be allowed to go on with oil, only replacing the lost screw.

5th. The men of the locomotive department should apply the red ticket form No. 2331, to those boxes which have not received any, and which should however be found in one of the following conditions:

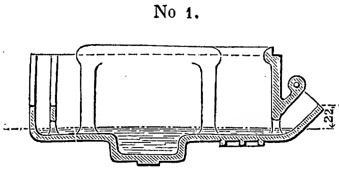
" 1. Boxes fitted for oil, but running with grease;

" 2. Boxes still running with oil, but bearing traces of heating, and the upper portion of which is no longer filled with grey grease.

" 6th. The greasers and examiners of intermediate stations should apply, with the greatest care, the two preceding clauses to the waggons P. L. M. brought back by foreign companies.

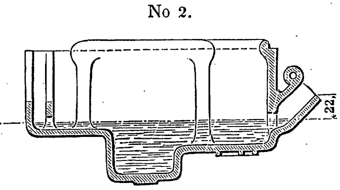
" 7th. Some of the boxes G — 8 — H, the first delivered, have shallow bottoms (see annexed sketch, No 1), which do not contain the quantity of oil necessary to insure lubrication.

No 1.



" These shallow bottoms are not numerous; they have been promptly replaced by others of more capacity (see annexed sketch, No 2).

No 2.



" The *Oullins* shops are about to cast new bottoms arranged internally and with the capacity of those of the boxes G—8—H, 1870, but adaptable to the former G—8—H boxes.

" Until these new bottoms are supplied in store, the shops installing the oil lubrication must allow the boxes with the old bottom No 1 and which have not yet been fitted for oil, to run on with grease.

"When the supply of bottoms is sufficient, the shops will take up again the alteration for those waggons having boxes with bottoms No. 1, but substituting for these latter the new ones supplied from *Oullins*. Further, they will make the same substitution on all the waggons with No. 1 bottoms, and which have been previously fitted for oil.

"8th. Until the completion of the replacing above indicated, the greasers and examiners should look after with special attention the old G — 8 — H boxes, furnished with No. 1 bottoms, so as to add oil if necessary; and, in exception of the clause 8th of instruction No. 145, the level of the oil will be kept only 0.40 of an inch below the mouth, for the old G — 8 — H boxes with No. 1 bottoms.

"9th. The making out of the red ticket 2331 (*Running with grease to be lifted after unloading*) does not indicate explicitly enough that the waggon must be sent to the shops to be lifted; thus certain stations continue to run these waggons so ticketed.

"The tickets delivered in future will be thus made out: "*To be put right after unloading, running with grease.*"

"In this manner the station people will be informed they should proceed for these vehicles as for those vehicles with a green ticket 2303 (386 to 390 of general order No 14).

"10th. It has been thought that one single ticket 2331 would be enough for each vehicle, whatever might be the number of heated boxes. This is a mistake; in the terms of 10 of instructions No. 144 and 4 of No. 145, a ticket must be placed over each box heating or heated.

4th Circular, No. 26 (Traffic) Service of stations and trains.

18th april 1872.

"Waggons bearing this ticket should, on no pretext, be left in service after unloading, and they will be proceeded with as is laid down in clauses 386 and following of general order No. 14.

"The greasing service in the stations and trains is exclusively confined to the locomotive and carriage and waggon departments.

"If by exception, the intervention of traffic people becomes necessary in certain stations, they should limit themselves to filling the grease boxes with the grease of the season.

"They may put oil in the bottoms of oil boxes, but without ever opening the grease compartments of these boxes.

No. **84** (page 100). *Fractures of axles of slow goods waggons in the nave.*

We read in this number:

" Running passengers and goods together is a working necessity. It presents however no danger at moderate speeds; but at high speeds the chances of axles breaking increase, above all for the goods stock, etc.

" Thus it is prudent to exclude *slow goods* waggons from all passenger trains the speed of which exceeds a certain limit. This is what has been done on the Méditerranée system. The limit is fixed at 31 miles an hour."

Instead of 31 miles, it should be 28 miles an hour, as we shall see.

First erratum.

But there must be a second, suppressing in its turn all limit of velocity.

This requires some explanations, instructive in more than one respect.

Breakages of axles, always very rare under passenger carriages, are on certain systems relatively very frequent under goods waggons, taking fully into account, as should be done, the difference in the respective quantities.

" According to returns made during a period of eleven years (from the beginning of 1857 to the end of 1867)" said the *Méditerranée* company in a letter adressed the 6th March 1868 to one of the engineers of the Government railway department; "*cinq* breakages only have taken place under third class carriages;" and then went on to add, making allusion to an observation made by an engineer: " It is thus wrongly that M. L.... considers the breakages of axles which have occurred as affecting the safety of the passengers." As if the safety of the passengers were not as much threatened by the breakage of an axle of a goods waggon included in the same train, as it would be by the breakage of a carriage axle !

The frequence of these breakages in goods waggons had on several occasions, disturbed the people of the districts served by the *Méditerranée* system, and their representatives called the attention of the Government Department to the subject. The Minister expressed himself thus in a dispatch of the 19th Nov. 1868, called forth by a discussion of the Council General of the Allier department:

" It results, in effect, from a statical return prepared in my offices, according to the returns furnished by the Railway Department, that from the month of September 1867 to the month of August 1868, 201 breakages took place on the *Paris* and *Méditerranée* lines, causing 40 breaks down, and 126 cases of running off.

" These figures appear to me to warrant the apprehensions of the Council."

Justly disturbed themselves by these more and more frequent breakages under goods waggons running in passenger trains, the company by a letter of the 8th January 1869, entered into an undertaking which the minister of Public

Works himself took cognisance of in the following dispatch, addressed to the Control Department, and forwarded by them to the Company.

Ministry of Public works.
—
General Board of Bridges and Highways and of Railways.
—
Railways.
—
Working section 2nd office.
—
Mediterranee Railways.
—
Admission of goods waggons with passenger trains.

" Paris, 26th feb. 1869.

" Sir, you addressed me on the 12th Jan. last a letter dated the 8th of the same month, by which the company of the *Méditerranée* lines makes known:

" 1st. That *goods waggons are no longer allowed* for some time past, in the trains 205 and 214 on the line from *Dijon* to *Belfort*, running at 31 miles an hour.

" 2nd. When, as soon as the opening of the summer service shortly, the speed of other trains *taking goods waggons will be brought down to* 28 *miles an hour at the utmost.*

3rd. That from the same period, the admission of slow goods waggons will be interdicted on the whole system in all trains running *above* 31 *miles an hour.*

" I have the honor, Sir, to acknowledge the receipt of this communication, and beg that you will *acquaint me with the reply of the company to the observations addressed by you to them, on the contradiction of terms in the two last paragraphs quoted above.*

" Accept, Sir, etc.,

" *The Minister of Agriculture, Commerce and Public Works.*"

" For the Minister and by authority:

" *The Counciller of State, Director-general of Bridges and Highways and Railways.*"

The company replied to this communication (a little tardily, the 20th May) by the following:

" Paris, 20th may 1869.

" Sir,

" I perceive that I have not replied to the communication that you have been good enough to make use of, accompanying ministerial dispatch, which points out a contradiction in the arrangements indicated in a letter addressed by the company to you on the 8th of January, relative to the EXCLUSION OF GOODS WAGGONS FROM TRAINS RUNNING AT A HIGHER SPEED THAN 28 MILES AN HOUR.

" The contradiction is in effect evident, and results from the substitution, by a slip of the pen, of the figure 31 instead of 28 in the third arrangement which were the object of my letter in question.

" In fact, the company quite intended from the day of opening of the summer service the admission of slow goods waggons should be interdicted on the whole system, in all trains the speed of which is higher than 28 *miles an hour;* and this is what was actually done.

" I am, Sir, etc.,

" *The Traffic-manager.*"

On the 22nd of May, the ministerial dispatch of the 26th Feb. and the above letter from the company, dated the 20th May, were, according to routine, communicated to the staff of the Railway department. They returned the 4th of June to the inspector general, signed by the engineers in chief and ordinary engineers charged to see the measure carried out. The 22nd of May, the letter of the company was forwarded to the minister, who took cognisance in these terms of the rectification made at his request by the company.

"Paris, 5th June 1869.

" Sir, in reply to my dispatch of the 26th of Feb. last, you transmitted to me, the 22nd of May following, a letter by which the *Méditerranée* Company rectifying a mistake which had slipped into a preceding communication, makes known that *from the opening of the summer service*, THE ADMISSION OF GOODS WAGGONS HAS BEEN INTERDICTED ON THE WHOLE SYSTEM OF LINES, IN ALL TRAINS THE SPEED OF WHICH IS ABOVE 28 MILES AN HOUR. Ministry of public works.

" I have the honor to acknowledge the receipt of this communication.

" Accept, Sir, etc.,

" *The Minister of Agriculture, Commerce and Public Works.*"

" For the Minister and by authority :

" *The Councillor of State, Director general of Bridges and Highways and Railways.*"

That is then what is quite understood : " *From the opening of the summer service* (1869), *the admission of goods waggons has been* INTERDICTED *on the whole system in all trains running above* 28 *miles an hour.* " The minister authenticates it, and in terms which certainly permit of no equivocation.

We may remark at once that the figure given in the ministerial despatches and communications of the company, is the *normal mean* speed taken from the service bill, approved every six months, by the minister, or of the " *graphique* " which is the synoptic rendering of that bill.

The number of trains containing carriages of the three classes, the speed of which thus defined exceeds, even only on a slight portion of the journey, the figure of 28 miles an hour is exceedingly restricted, as may be ascertained by looking over pages 116-121 of the book of the *Running of the trains;* so *the interdiction* certified by the minister had in reality but small effect. It was rather a first step in a good direction than any important satisfaction as regards safety. And that all the more, as the general regulation No. 4 (clause 24), authorising in case of delay an increase of 50 per cent. in the mean normal speed, we arrive at 42 miles for the speed which trains can be run at, containing slow goods waggons. This is certainly far too high for waggons which so often have concealed fractures, taking half the section and sometimes more.

The undertaking taken by the company, officially certified by the minister, in which he caused an error to be rectified, does it bind the company? If it were not so, what would be the object of either the undertaking itself, or the ministerial dispatch certifying it, and that certifying the rectification?

The general regulations themselves for working would thus be deprived of all sanction, for these regulations are nothing but the propositions of the company, rectified and modified if there is room, and approved by the Minister.

This is moreover what is established, in these terms, by a ministerial dispatch of the 20th Jan. 1872, addressed to the inspector general of tbe Control department :

" A regulation of the company, by virtue of the approval given thereto by the minister of public works, *has quite as much force as an order emanating directly from the higher board itself.* "

There is further :

The 15th of June 1870, train 228 ran off the line between *Ambérieux* and *Ambronay* (Ain), on account of the breakage in the nave of an axle of a waggon S.

The report of the engineer of mines on this accident (which by the way had nothing serious in itself) concluded thus : " According *to the step taken by the company in* 1869, *approved by the minister's letter of the* 26*th Feb.* 1869, this speed of 28 miles an hour ought not to have been exceeded. Neither the *Ambérieux* station master, nor the driver took any notice of it : they appear not to have received the necessary instructions. *Proceedings have been instituted against them,* with the option of transferring the responsibility on those from whom they should have received instruction should none have been issued : which will be shown by the conclusion of this affair. "

Lyons, 4th July, 1870.

" *The ordinary engineer of Mines.*"

This report, endorsed by the engineer in chief of the Control, and by the inspector general, was transmitted the 11th of July 1870 to the *Board.* The Court of *Belley* (Ain) received on its part, the routine advice as to the sequel of the complaint drawn up by the surveying commissary, advice thus drawn up :

" The ordinary engineer of mines, considering that the railway company of the P. L. M., declared by its letters of the 8th Jan. and 20th May 1869, that thence forth the speed of passenger-trains taking goods waggons should be brought down to 28 miles at the utmost; that this step was approved by the minister the 26th Feb. 1869;

" Considering that the high speed of trains increases the risks of axles breaking, is of opinion that there are grounds for instituting judicial prosecutions against N., deputy station master, and N., driver, in virtue of the ministerial

dispatch of the 26th. Feb. 1869, which officially certifies the maximum speed of trains containing passenger carriages and slow goods waggons, and of the articles 79 of the regulation order of the 15th Nov. 1846, and 21 of the law of the 15th Nov. 1845."

Possessed of the administrative report of the 4th of July, the Board was thus perfectly aware of the sequel given by the Control to what it had under consideration — rightly or wrongly matters little — as a violation of the undertaking of the 8th Jan. 1869, approved and rectified by the minister the 26th Febr. and 6th June following.

The Board acknowledged the receipt of this report, without making any observation.

Every one was thus agreed.

Let us proceed:

The 15th Jan. 1872, the Minister of public works addressed the following letter to the examining magistrate of the court of *Sens* (Yonne):

Ministry of Public Works.

—

General direction of Bridges and Highways and Railways.

Versailles, 15th. Jan. 1872.

Sir, by the letter which you have done me the honour of writing to me on the 9th. this month, you ask my opinion on divers questions brought up by the inquiry with which you are charged in order to find out the causes of the accident which took place the 16th of Dec. last, near *Champigny* on the *Paris* and *Méditerranée* line. You desire to know, particularly, if the dispatch addressed the 27th Feb. 1869, by the minister of public works to the inspector general of the Control is a ministerial decision, and if it is of an obligatory character, such that any infraction of its terms is an offence repressed and punished by article 21 of the law of the 15th July 1845, for the regulation of railways.

" On this last point I have to say that the letter of the 26th Febr. 1869, *cannot be considered as a ministerial decision, and that the marginal note of the director of the Control cannot give it that character.*

The terms of that letter sufficiently point out that it had no OTHER END, and could have no OTHER EFFECT, than to acknowledge the receipt from the director of the Control of a communication by which the company made known to him measures which it had taken on its own account. I will add that the observation which concludes the dispatch of the 26th of Feb. *had for* SOLE OBJECT *to point out a material error which the company hastened to rectify*, by substituting the figure 28 miles for the figure 31, brought forward in the letter in question."

. . . .

Signed: *The Minister of Public Works.*

Everything is changed then?

The engagement of the 8th of Jan. 1869, the ministerial dispatch of the 5th June which officially certifies it, the dispatch of the 5th June which certifies the presented rectification, what have they all come to?

The dispatch of the 26th Feb. "*cannot be considered as a decision.* (!)" As what should it be *considered* then? But the undertaking remains, at least... If the dispatch does not say positively the contrary, it lets it be understood so.

But if the engagement is only a "*communication*" without import, a dead letter, of what use to take it, of what use to acknowledge the receipt of it? Of what use to have an error rectified in it? Does one rectify nothing? And if all that is nothing, if the dispatch of the 26th Feb. 1869 had neither end, effect, nor object, should it not have been so stated at the time, in 1869, and not in 1872, at the very moment when the consequences of the undertaking were being felt?

Opinions have then changed; people have assuredly a right to do so. But is it not singular that the Control (where there had been no change), was not even informed of this sudden change? Now, the Control only became aware thereof very late on, and in the most indirect way, that is to say by the publication made *by the company* of the above letter!

And once more, if the ministerial dispatches of the 26th Feb. and 6th June have, according to that of the 15 Jan. 1872, no bearing, no sense, no effect, why have writen them? But seeing that was done, how say, in 1872, that in writing those dispatches in 1869 nothing was intended to be said?

The reason is that in 1869, people wished exactly to say what they said, and to do what they did. But in 1872, they regretted it. They would have wished nothing said, nothing written especially. It was a question in 1869 of the safety of the public; in 1872 of an interest of another nature....

But what had occurred in the interval?

This:

On the 16th Sept. 1871 a train ran off the line at *Champigny* (Yonne). Ten passengers were killed, a greater number injured. The accident was caused by the fracture of the axle of a coal waggon, which separating from the frame, rode over the wheels of the passenger carriages following, broke their couplings, sent them off the line, and upset them.

Tardily apprised (and by a message which made no mention even of injuries), the engineer of the Control (Railway Department) went to the spot, studied minutely the material circumstances of the accident, and rendered an account of it on the 27th to the inspector general in a report forwarded on to the minister *the very same day*, the 27th, in order to meet the natural anxiety of the Minister.

Every time an accident attended by death or injury occurs on a railway, the Control service, makes, in the terms of the regulations, two reports quite distinct: one, the administrative report, the elements of which are obtained by actual inspection of the locality, is addressed as promptly as possible to the minister; the other, in which is discussed the question often so delicate of the responsibility involved, and which announces the views of the engineers as to the proceedings to be taken, is adressed to the Court within the juridiction of which the accident happened. The character of this second report is consideration, just as the character of the first, which is above all a recital of facts, is as much as possible : urgence.

It is then quite simple that when prosecutions are proposed in a report to the Court, there may be in no way any question thereof in the administrative report preceding; first, because there is no question thereof in that report, and after for this excellent reason, that the engineer in drawing up that previous report, is in no way aware whether he will be led or not to propose prosecutions.

It was sought however, to put the Control in contradiction with itself in the *Champigny* affair, under the pretext that the first report, the administrative one brought forward no charges, while the second, the report to the Court, made them and concluded in favour of prosecution. It was necessary, apparently, to announce in advance to the administration, that charges would be brought and prosecutions would be proposed to the Court, and that, several days before knowing whether there were in effect, any charges, and whether there should be any prosecutions! (*)

This singular complaint might still have passed, if it had only been uttered by the accused persons. A defense has very wide rights, and makes use of them; and to certain of its arguments, there is always a corrective — the sort of suspicion, legitimate enough, which hangs over them. But what is hardly explained, is the echo which these imputations found in regions where serene impartiality should reign, a clear notion of rights and duties, a profound and pure feeling of the fundamental conditions of the public service and the guarantees due to the dignity of functionaries.

Let us close this parenthesis.

The magistrates of *Sens* receive the regulation reports, and hold their inquiry.

(*) It was even said (what was not said) that the engineer had had to make, — *by order*, — a second report which was absolutely the counterpart of the first! How likely that is! And these reports have been hawked about by those who ought better than any one, to know the engineers, and more than any one to resent every attack on their justly famed professional dignity! The engineer accused of having thus yielded to unworthy pressure is well known, not only in the corps to which he belongs, but also in the scientific world; and all those acquainted with him know whether the thoughtless imputation of which he is the object could fall more inappropriately. Chief and subordinate were able to meet it with perfect contempt.

They verify that the train 24, a *direct* train from *Marseille* to *Paris*, stopping only at 50 stations out of 130, only taking on a considerable portion of its run, first class passengers, almost an express, in a word, has its mean speed regulated, in certain points, by the service time-table, at more than 28 miles an hour; that thus no slow goods waggon ought to have been contained therein, on the portions where the velocity is regulated at more than 28 miles an hour; that the accident was caused by the presence in the train of a coal waggon Sf., an axle of which, faulty from an old crack in the nave, broke; that in the terms of the undertaking of the 8th Jan. 1869, of the interdiction which the minister certified on the 26th Feb. and 6th June 1869 (in terms perfectly clear and accepted more than three years before, without any objection on the part of the company) the waggon Sf, put on to the train 24 at *Lyons*, should not have been there. They state again, that without the fatal presence of that waggon, the catastrophe would not have taken place. They verify again that, contrary to his assertions, the director had given no instructions for the insuring the carrying out of the undertaking of the 8th Jan. 1869; that thereby the responsibility of the violation and of its consequences devolves on him; that the fact falls indeed, independently of all infraction, under the effect of the article 19 of the law of the 13th July 1845, an article the close meshes of which allow no act or omission fatal in its consequences to escape (*).

Neither the active proceedings of the company, nor the ministerial dispatch of the 15th Jan. were able to prevent the director being proceeded against criminally.

This decision was the signal for the execution of a plan followed out with remarkable combination and perseverance. Not daring, for reasons, to lay the blame on justice, they did so on the Control.

" For it is to you, my sister, that this language is addressed. "

It is not the examining magistrate who verified that, if it is not in the nature of things for a director to be responsible, his responsibility is attacked in this way, that he did nothing to insure the measure announced by him, as in full course of execution!

It is not the examining magistrate who sends the accused before the court!

If the address of the prosecutor is against, it is not the public minister who will have spoken!

(*) This article is drawn up as follows :

« Whosoever by unskilfulness, imprudence, carelessness, negligence or non-observance of the laws or regulations shall have involuntarily caused on a railway, or in the stations an accident causing injury, shall be punished with eight days imprisonment, and a fine of from £ 2 to £ 40.

« If the accident causes the death of one person or more the imprisonment will be from six months to five years, and the fine from £ 2 to £ 40."

In the decree concluding the *Champigny* accident, the *Paris* Court of appeal, took into consideration, instead of this article, the simple penalty of common law. Engineer-in-chief *Lamé Fleury* has brought forward this unintelligible error, in his annotated official report.

If a conviction ensures, it is not the court who will have pronounced!

And everything is agitated in ordinary and higher regions.

And they go to the Head of the State (then M. *Thiers*) to whom they declare that the Control department (always the Control), personified in an individual, emits this strange theory that the " manager of the company ought to be rendered personally responsible for all the accidents which occur on the railway! "

Here a significant incident takes its place.

Struck by the number, the activity, and the diversity of the influences brought to bear, of the intrigues brought to light, the local court transmits the case to its head, the *procureur général* of the Court of Appeal at *Paris*, who after personally examining into the matter, gives his *substitute* the order to prosecute the manager.

Ministry of Public Works.

General direction of Bridges and Highways and of Railways.

Working Department.

Let us now take further from the company's publication (*), a ministerial dispatch addressed, on the urgent demand of the company, to the *procureur général* of the Court of Appeal:

Versailles, March 18th 1872.

" Monsieur le Procureur général, by the letter which you did me the honour of writing to me on the 16th inst., you communicate to me, in requesting me to reply thereto as soon as possible, a letter in which the chairman of the *Lyons-Méditerranée* railway begs you to submit a question to me on a point which has been contested in the informations relative to the *Champigny* accident.

" This question is as follows:

" *Does there exist in companies rolling-stock and ought there to be by the regulations an absolute distinction between low speed rolling-stock, and high speed do.; and are not* WAGGONS OF EVERY KIND *and ought they not necessarily to be placed in high speed and low speed trains, according as the sender requires either of these two modes of transport for dispatches involving the use of such or such a type of vehicle, and is this way of proceeding in conformity with the regulations?*

" I hasten, Sir, to address you my reply to the question of the chairman of the company. That reply can only be founded on the terms of the decree of the 15th Nov. 1846, which must always be referred to, when information is required as to the rules imposed on the companies for the working of lines of railway.

Here follows a pure and simple reproduction of the articles 8, 10, 18 and 22 of the decree of 1846.

The dispatch continues in these terms:

" Such are, Sir, the only limitations of the decree of 1846 which are applicable

(*) Like the preceding, this dispatch only became known through the company.

to rolling-stock entering into the composition of mixed trains, passenger, and goods running at passenger speed.

" It results from the text of these articles that no absolute distinction is established between low-speed stock and high-speed ditto, and that it is enough for a waggon to satisfy the conditions recalled above, *for it to be admissible in a mixed train running at passenger speed.* And, in effect, the schedule leaves to the sender, for the transport of any goods, the choice between slow and fast trains, and when the latter is chosen, the dispatch must be made, in virtue of the 50th article of the aforesaid schedule, by the first passenger train *including carriages of all classes.*

" The companies may, consequently, without contravening the regulations, place in passenger-trains, when dispatch by a fast train is called for, all the types of goods-waggons, according to the nature of the objects to be carried, and that without any other restriction than the one resulting from the above-mentioned articles 8, 18 and 22 of the decree of the 15th Nov. 1856.

" I beg you, to be good enough, in conformity with the request of the chairman of the company, to transmit this reply to the court of *Sens*, so that it may reach in due time.

" I include with this, the letter you were good enough to send me. "

" *The Minister of Public Works.*"

Thus, according to the company, " waggons of every kind " may and ought to be placed in *fast* trains !

Any waggon, a coal-truck, for example, on axles of No. 2 type might be placed even in an express, running at 40 miles an hour, and at $\frac{3}{2}\ 40 = 60$ miles an hour in case of being late?

Is this what is desired to be said? If so, very well! it is a gross error; what is said has never been done, is never done! They are not so imprudent as they would make believe, for the requirements of the case.

Moreover, the ministerial letter itself rectifies implicitly the assertion made, under the form of inquiry, by the company. It is not a question of *fast trains*, but of "*passenger trains including carriages of all classes* (*)."

" *As to the distinction between high speed and low-speed rolling stock,* " it doubtless exists only in the imagination of the Control department?

(*) There is occasion to dwell very particularly, says M. *Lamé-Fleury* (*a*), on this fact, that for goods, *fast* such as it is defined by the schedule, article 50, is not the speed of express passenger trains, as is commonly thought, but that of trains including carriages of all classes, that is to say ordinary or mixed trains.

(*a*) *Code annoté.* 2nd edition, page 152.

Let us open the " Classification of the engines, tenders, carriages, and waggons of the *Paris-Lyons-Méditerranée* railway (1st Jan. 1872). What do we find therein?

1st. Page 27. In large letters, this heading: " carriages and *waggons for fast trains.*"

2nd. Page 35. " Recapitulation of the carriages and *waggons for fast trains.*"

3rd. Page 37. In letters no less large, " *waggons for slow trains.*"

4th. Page 49. " Recapitulation of the *waggons for slow trains.*"

5th. Pages 50 and 51. " *Carriages and waggons for fast trains*; *waggons for slow trains.*"

And what says the locomotive department order, brought forward farther back (page 746, lines 19-20)? " These modifications will be applied first to *slow waggons,* and later to carriages and *waggons for fast trains.*"

And article 213 of general order No. 24 (page 79):

Vehicles for fast trains.........	Carriages, luggage or parcel (*) vans, travelling post-offices or post vans with three axles; the same vehicles with two axles, brakes, horse-boxes, trucks. »
Vehicles for slow trains........	Goods-waggons of every nature, for coal or ballast.

And now let us look elsewhere.

What shall we find in the general order No. 12 of the Eastern of France, fixing the rules to be followed for the use of the rolling stock, pages 24 and 25? These two headings:

" 1st. Stock for high speed. "

" 2nd. Stock for low speeds. "

And what does the director's report for 1872 of the Midi railway say, page 93, table XV? " *High speed waggons. Low speed waggons,* etc... " It is not doubtless worth while multiplying these examples.

There are, then, waggons for *high speeds,* and waggons for *low speeds!*

It is not then the Control department who says it, nor who has established " a distinction between *high and low speed stock.*" It is the company. It is common sense. The men who manipulate the stock in the station-yards would stare if they knew that such a point could have been seriously brought into question!

There is thus something else than the decree of 1846, a decree of which it was probably superfluous to recall to the court the old and well known arrangements. There is, in fact, " a distinction, " which turns up at each step in the documents of the companies. Only the directors were not aware of it.

(*) La " *Messagerie* " is goods dispatched at fast rates.

See the same general order:

1st. The § 2 (pages 40 and following) entitled: " Special arrangements for the service of *passengers and fast goods* trains. "

2nd. The § 3 (pages 59 and following) entitled: " Special arrangements for the service of goods rains. "

3rd. The article 366 (pages 143 and following), etc., etc.

Now, that a waggon belonging to the category " *low speed* " may run in passenger trains, who denies it?

It is a question of prudence, that is to say of speed.

The speed enhances the chances of the total breakage of an axle already cracked; and it enhances quite otherwise the effects of that breakage, as was seen at *Champigny*.

Once more, a coal waggon for example, would, especially if it were on axles which had every suspicion of containing hidden fractures, never be placed in an express train, running fast, and with long distances between the stoppages! What has been never dreamed of in an *express*, is in the highest degree imprudent in a *direct* train running at 30 miles an hour, that is to say 45 miles in case of delay. In a word, there is a limit of speed to fix, and beyond which slow waggon ought to be excluded. This is what the company, warned by the constantly increasing number of breakages, within the nave, of its slow waggon axles, comprehended; this is what it did by that undertaking of the 8th January 1869, so singularly and so unluckily resolved into thin air!

If it be desired to account a little more closely for the motives for this " distinction " established *by the companies* between *high and low speed* waggons?

If it be desired to know why there is an almost absolute certainty that the axles of high speed stock are sound, inside the nave, as well as else where; and why there is, on the contrary, a very *serious* probability that the identical axles in the *low speed* stock, particularly, if they have a faulty shape, as have all those of the *Méditerranée* system (see the following note), are affected by partial fractures, of more or less standing, of greater or less extent; so that (as experience daily shows), at a high speed total breakage becomes imminent?

Here in two words, are the causes of such different conditions in the two categories of axles:

1st. *Low speed* stock is, often, more loaded.

2nd. Its load is often very unequally divided between the two axles, on account of wrong loading, of shaking out of place during the journey by the action of shocks, and so on.

3rd. The suspension springs are much shorter, and much stiffer in low speed stock.

4th. It has no play in the hornplates for tke axle-boxes, nor joints (hanging links) for the suspension, so that the shocks are transmitted directly from the guardplates to the axles.

5th. The drawing and buffing springs are more rigid.

6th. Goods trains are formed of a very great number of waggons (up to 80), which undergo, on that account, on starting and stopping, which are so frequent for these trains, violent shocks.

7th. Low speed waggons are subjected also, during station operations to continual shocks.

8th. They are constantly running through siding curves, on account of the frequency of these operations, wherein the axles suffer severely, on account of the absence of play; and, for some, coal-waggons especially, the position is further aggravated by their frequently having to run over branches into collieries, with much sharper curves still than those of the main line siding.

9th. The strain on the axles and their predisposition to partial fracture are, as all practical men know, greatly increased by the existence of a brake. Now as its mark shows, the S*f* of train 24 was a brake-waggon.

These four last causes are *the most serious of all.*

Lastly, when the tyres of the wheels of *high speed* stock are too much worn, they are removed in order to be placed under *low speed* waggons, where they continue their service; which is all very right. But this step, which seems at first a pledge given to safety, what does it signify, so long as these waggons may be included in passenger-trains, even " direct ones? "

Let us continue our narrative.

Justice does its work, and the accused is condemned.

And then, the concert of recriminations, and the work of demolition commence in style; a manager convicted! is it possible? Equality before the law! is it bearable? But the respect for justice.... Well! justice has been deceived (to say that justice has allowed itself to be deceived, is not perhaps very becoming). Has been deceived by whom? By the Control Department, of course.

The Control Department did everything: " saw and circumvented the judges!" This report is promulgated by those very ones who particularly well know that if the Control Department " saw the judges, " it was by constraint, by reason of summonses from which the superior administration declared that it could in no way withdraw, and after having been even threatened with the application of the criminal law!

This is, not precisely how history is written, but how it is *told*.

That the company, convicted in the court of *première instance*, should have used every means to get an acquittal on appeal, was quite natural. What was less so (although it really ought to have been expected after the letters of the 15th Jan. and the 18th March 1872), is the support it found.

An acquittal was necessary, and necessary at any cost! To get the conviction reversed was difficult (*), but the merit would only be all the greater.

(*) This difficulty came out enough (in spite of some errors of detail in the recitals) from the very drawing up of the judgment, and *more still from the text of the decision annulling it.*

The argument so... hasarded from the pretended nullity of the undertaking had no success before the judges of the first court; something else had to be found.

A certain amount of confusion, casting incertainty and perplexity into peoples' mind, is not a means to be despised.

To misrepresent everything, to confuse everything, to render everything obscure, helps at times to get out of a scrape. It is said that an intelligent mollusk, the cuttle fish, when pursued, disturbs the water by a jet of ink, and thus surrounds itself with a thick cloud which favours its retreat. The cuttle-fish has not the monopoly of that proceeding.

The 20th April 1872, the followiug decision was notified to the company (that is to say to the Court of *Paris law*), and to the inspector general of the Control Department.

" Versailles, the 20th April 1872.

Ministry of Public Works.
—
Direction general of Bridges and Highways and Railways.
—
Railways.
—
Working Division.

" Sir, in the report you addressed to me on the 27th Sept. 1871, on the subject of the *Champigny* accident, you expressed the opinion that: the article 24 of the general regulations of the *Méditerranée* Company, which allows drivers to increase by 50 per cent, the speed given in the time bill, ought, according to you, to cease to be applicable to *passenger trains* containing *low speed waggons*.

" I have submitted the question to the Commission for Railway regulations. The commission, during its sitting of the 19th March last, decided first and foremost that the 24th article of the general regulation No. 4 is quite applicable to all the trains, so that, for those the running speed of which is fixed normally at 28 miles an hour, that speed may legally, in case of being behind, be carried to the absolute maximum of 42 miles an hour, even if they contain waggons loaded with *slow goods;* The commission thought, nevertheless, that, *in the interest of the public safety, it would be necessary to prescribe a lowering of the limit provided by the article* 24 *of the general regulation No.* 4, a lowering of which would be applied to passenger-trains containing *waggons loaded with slow goods!* which are generally more loaded than waggons carrying fast goods. The commission observes, on the other hand, that *it does not appear possible to adopt as an absolute maximum of the speed of passenger-trains, containing waggons loaded with slow goods, the limit of* 28 *miles an hour proposed by the Control Department; that in effect, the fixing of a similar maximum would involve necessarily the diminution of the normal speed of the trains which would be subjected to it;* that the result would be a disturbance of the service, and a modification in the working all the more objectionable that the tendency of the government and of the public has always been to call for an increase in the rate of travelling of

passenger and goods-trains. The commission has been led thus to express the opinion that by admitting a normal speed of 28 miles an hour for *passenger-trains* containing waggons loaded with slow goods, a difference of 20 per cent, might be authorised without disadvantage between that normal speed and the maximum speed in case of being late, and that maximum consequently carried to 33,6 miles an hour.

" By a decision of this date, I have approved of this opinion, and I have in consequence decided *that the normal speed of running of passenger-trains containing waggons loaded with slow goods, should be fixed at* 28 *miles an hour*, and could not in any case, *even that of being behind*, be carried more than 33,6 miles an hour.

" In conformity with the advice of the commission, *these arrangements are not to be applied to passenger trains containing waggons loaded with cattle, goods and any articles whatever, dispatched as fast goods.* These *waggons* will continue, by the application of the article No. 50 of the schedule, to be admitted into passenger trains containing carriages of all classes, and running at the speed regulated by the time-bills, and the regulations approved by the government.

" I think I should add that the admission of vehicles of every sort into trains carrying passengers, whether these vehicles are loaded with slow goods, or with fast goods, remains, in all cases, subordinate to the conditions prescribed by articles 8, 10 and 22, of the regulation decision of the 10th November 1846.

" I beg of you to notify the present decision to the engineers of your service, and to see that it is carried out.

" I notify it myself to the company.

" *The Minister of Public Works.*"

There is not an engineer, not a lawyer, whose first word after reading this decision was not: " what is the meaning of this? What is the connection of this official act with the preceding ones, and with the facts which have led thereto?"

New prescriptions cannot modify by retrospective effect, elements which the law has acted on. A posterior decision can have no value, excepting in the way of interpretation. Is this the case here?

If the document which intervenes seems at first singularly obscure, light breaks in on it afterwards by degrees, and its true bearing is developed!

This decision keeps absolute silence as to the undertaking of the 8th of February 1869, and as to the ministerial letters of the 26th of February and 5th June 1869. This silence is connected with a new system, adopted by the company.

The ministry had let it be understood that the undertaking was *nil*, that it did not bind the company; when lo! one fine day, the latter, changing its tactics, insinuates that the undertaking was in no way violated by the composition of the train 24 of the 16th September 1871!

It is from this new point of view that the act of the 20th April 1872, is drawn up, equally remarkable both by what it says, and what it does not.

It seems at first sight, to lay down for the future an absolute limit to the speed of passenger trains containing goods waggons with suspicious axles: 33,6 miles an hour, instead of 42 miles. Here then is a *fast* limit of 33,6 miles? 8,4 miles are thus gained, a difference of a certain value, the destructive effects increasing as the square of the speed?

Well! nothing of the sort! This prescription is, a few lines lower down (4th paragraph), reduced to naught! By the most singular of phenomena, a question of safety is found quite quietly, without seeming to be touched on, transformed into. . a question of *tariff*!

The question is the protection of passengers against the breakages of axles, so frequent in the slow stock of the *Méditerranée*, and which may prove most disastrous.

But lo! and behold! that in the terms of the decision of the 20th April, it is no longer a question of the waggon, nor of its axles, nor of their hidden fractures! All that is of small consequence! What is of consequence, is... *the tariff paid by the goods carried!* The carriage of the same object, by the same waggon, in passenger-trains the speed of which exceeds the fixed limit, is *prohibited* and *dangerous* if the tariff is low; it is *unobjectionable* and *allowed* if the tariff is high! And if the waggon is empty (which in no way prevents it being dangerous should it have a cracked axle), how is the decision to be applied? To what category, — slow or fast — belongs this load, which does not exist?

Here is any *slow* waggon, a coal-truck for example, like the Sf of train 24; it is desired to couple it on to a fast train, what hinders! A porter sticks on a label bearing the word: *fast*, which signifies that the *tariff* paid by the goods is that of *fast*; and the thing is done. By the decision of the 20th April 1872, the waggon is exorcised! Had it an axle half cracked through in the nave, there is no longer any danger... for the company, that is to say, no more responsibility!

Far from us however the thought of suspecting the label. The label will be right, for the quite simple reason that the company will not do goods dispatched by fast train the favour of carrying them at the slow tariff. So that altogether, in seeming to prescribe something, as to limit of speed, the decision of the 20th April only aims at an infinitely small matter (*), and it touches the absolutely innocent *goods*, when it is the *waggon* that is in question!

But the following passes everything.

" The commission has pointed out, on the other hand, that it did not appear

(*) The dispatch by *fast train* of goods paying low speed tariff is such a commercial absurdity, that it may be left to the companies; they have only recourse to it in the *extremely rare* cases where

possible to adopt as absolute maximum of the running speed of passenger-trains containing *waggons loaded with slow goods*, the limit of 28 miles an hour, PROPOSED BY THE CONTROL DEPARTMENT; that in effect the fixing of such maximum would necessarily involve a reduction in the normal speed of the trains subjected to it, etc. "

This is incredible! Really, — the commission is quite sure of it, — the Control Department proposed to fix a limit to the speed of passenger-trains containing waggons *loaded with slow goods?*

The Control Department (like the company and the ministry in 1869) wished to exclude from trains running at more than 28 miles an hour, SLOW WAGGONS, and it fully stated why. When lo! to hear the commission, and the decision of the 29th of April it is GOODS at the slow tariff it desires to exclude!

Thus, in order to refute the control, the commission, which has all the elements, all the reports under its eyes, commences by making the control say quite the contrary to what it did say!

Let who can understand and explain such an *error* (for it must be supposed an error); but it will be admitted to be as incomprehensible as little excusable (*).

The Control Department states and writes most fully: *waggon*; the commission reads and repeats: *goods*. The Control Department speaks of the *axles* of slow waggons; the commission understands and repeats: *slow tariff!* and on that, it goes on.

Useless, certainly, to insist!

But why this confusion between the waggon and the goods, a confusion already seen to dawn, but timidly, in the despatch of the 13th of March?

Did it then serve some purpose? Oh! certainly, and a great deal, at a given moment. First, it gets rid of all that is troublesome. Not only the undertaking of the 8th January, the dispatches of the 26th February and 5th June no longer exist, but they even, as it would seem, never did exist! It is much more simple so! Then it works in with the companies' new system; it sanctions this astounding

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it is to their advantage : in order to expedite the arrival of goods detained by their fault, to complete a train, some times to clear a station, etc.

Is an exemple required? According to the return published in 1872 by the Midi directors, the total mileage of " low speed " waggons on that system, is thus divided among the three categories trains :

Goods trains	86,2
Mixed do	13,1
Passenger do	0,7
	100,0

and this figure of 0,7 per cent certainly includes return-empties!

(*) It is necessary to point out that the composition of the commission has been modified since the drawing up of this strange opinion, the responsibility of which cannot of course fall on the new members.

change of the question of safety into a question of tariff, that is to say what before was hardly dared to be expressed, so much did it seem the last resource of an advocate at a stand, almost a wager!

And so, what happens?

In the matter of railway-working, all ministerial decisions, relative to points having a general character, are, by right, extended to all lines. Nothing of the sort for that of the 20th April. It remains special to the *Méditerranée* system: it is an exception unique of its kind; its special object once attained, it is thought of no more. That is readily understood (*).

There is, in that dispatch, an other portion of a sentence, particularly significative, this: " THESE WAGGONS *will continue by the application of article* 50 *of the schedule, etc., etc...* " It completes incidentally, in a discreet form and with a light touch the sanction given to the company's system of defense; it introduces, in the matter of technical working and of control, an order of ideas as unforeseen as new.

What says this article?

" Animals, food-stuffs, merchandise and articles of any sort to go by fast trains, are dispatched by the first passenger-train *containing carriages of all classes*, and corresponding with their destinations, provided they have been handed in three hours before the departure of the train. "

Where then is it a question of *waggon?* Is it by prescribing the *goods* to be taken if presented to pay for a fast train, the schedule prescribes loading it on a *slow waggon?* It was undertaken on the 8th January 1869, not to refuse any goods, not to reduce the speed of any train, but simply to load those goods on a *fast waggon*, should the speed of the train exceed 28 miles an hour.

What then has the schedule of conditions to do in this? To introduce it, it must be treated (and that is the most serious part) as the report of the Control Department was treated. Its text must be altered. It must be made to say, *waggon*, when it says : *goods;* when it only deals and can only deal with the goods and not the vehicle!

Once such a line entered on, where will a stop be made?

The Court had not, as may be conceived, the idea of referring to the texts, of testing the accuracy of the summons.

(*). The requests for instructions as to the carrying out of this act have had no reply.

This schedule of conditions, so curiously invoked, so completely out of the question in the matter, let us see also, in passing, what is its authority fundamentally, notably how article 50 (*the real one*) is carried out:

This article 50, first, it did not apply to the train 24, which was not a train of all classes " seeing that it does not take second and third class carriages for a great portion of its journey.

The minister authorises and prescribes, as to what regards the composition of the trains, all the arrangements which result from a simple economical interest (which is often only the company's own), and *a fortiori* those which the safety of the public requires; and by regulating the composition and the running of the trains in virtue of the headings III and IV of the decree of the 15th Nov. 1846, it pays little enough attention to the restrictions which result therefrom for the application of article 50 of the schedule of conditions.

These restrictions, these derogations indeed, proposed by the Control Department and approved by the ministry, by application of article 29, 60 and 69 of the decree of the 15th Nov. 1846, without *any one whatever* having ever dreamed of opposing the conditions of the schedule to them, who would dare to deny them? This train 24, for example, which only takes for a great portion of its journey *first class* passengers, is it not a derogation of itself, and a derogation which the minister has the right to authorise (art. 43 of the schedule of conditions: art. 27 of the decree of 1846)? And the train 25, quoted by the *Sens* judgment which, according to the guide-book, " does not take food stuffs, carriages, horses, or cattle over the whole of the part of its journey comprised between *Paris* and *Lyons?* " What a derogation! And the " train 617, which takes neither horses nor cattle between *St. Germain-des-Fossés* and *Lyons*, etc.," derogation! And the exclusions resulting from the dangerous or inconvenient nature of the matters carried, powders, fulminates, long bars of iron, long timber, casks of blood etc., etc.! Derogations! And if the train is full to the maximum of 24 vehicles, fixed by the decree of 1846! Postponement, derogation!

Derogations perfectly legal, I repeat, for the minister has authorised them in the legitimate exercise of his powers.

The shedule of conditions, — who is ignorant of it? — a simple appendix to the act of concession, is not a regulation to which the penal sanction of the law of the 15th July 1845 applies. Article 70 of the schedule of conditions attributes *to the councils* of the prefecture the knowledge of the disputes which may arise between the ministry and the companies on the subject of the carrying out and interpretation of the schedule of conditions; and the heading II (art. 12) of the law of 1845 defines expressly the contraventions subject to the penality decreed by article 14 (clauses of the schedule of conditions affecting navigation, the viability of the roads, the free passage of waters...)

Of the kind, the theory of passive obedience to the article 50, so ingeniously...

amended, of the schedule of conditions, takes, for the needs of the cause, proportions really epic, if one does go a little further into the causes of the catastrophe of *Champigny*.

" Thus " said much pretty justice, at *Sens*, summing up the argument of the company, " this is your thesis; you could not, you say, refuse *those goods*, brought for dispatch *within the regulation limit of time*, by fast train."

The reply comes of itself.

" Well? " continued much pretty justice, " first the article 50 does not apply to the train 24; further, it was not a question of refusing the goods, but of placing them in a *fast* waggon, that is to say in one of those vans of series D, of which the train 24 already contained five.

" But far more, that *merchandise* was not *goods!* There was neither a question of tariff, nor of any third party dispatching; there was only *the company* carrying, in defiance of its undertaking and of the safety of the public (who have so dearly paid for it), an article *belonging to itself* in a low speed waggon, and what waggon, a coal-truck, the most suspicious of all, with a brake, and mounted on axles of type No. 2, the most suspicious of the types! "

That is in a few words, the history of article 50, in its relations with the undertaking of the 8th January 1869, the ministerial dispatches of the 26th February and 5th June 1869, and those of the 18th March and 20th April 1872.

The decision of the 20th of April had, on appeal, more success than had, in the first instance, the letters of the 15th January and 18th of March. The judgment of the court below was reversed, the manager of the line acquitted, without costs.

We cannot here, from want of space, reproduce the judgment and the reversal; but these documents have been published in M. *Lamé-Fleury's Bulletin Annoté*.

The truth, were it evident, may be veiled, submerged, but for a time. Plain common-sense ends by getting its rights. Now what remains of all that chaos of quibbles, acts which nullify each other, contradictory interpretations, altered texts, of calculated confusion? There remains this, whatever may be done: an undertaking entered into, recorded and verified by the minister; this undertaking violated; a disaster! Condemned by the lower court, acquitted on appeal, has the company also been acquitted by that tribunal which each carries in himself, from which no act escapes?

However, the acquittal on appeal was not sufficient for the company. Elated by its triumph, strong in the support, so earnest, it had found, it pursued with

fresh ardour what had become its sole aim, the removal of the inspector-general of the Control Department.

Why not also, why not rather that of the officials who had prosecuted the company? Because although they are not irremovable like the judges who condemned, that would have been a little more difficult.

To disclaim the head of a department, having at the very least experience, and to whom is accorded perhaps a certain authority in these matters; to disclaim him because such was the *company's pleasure;* to disclaim him because testifying under oath, he told the truth before justice, that is hard, and a thing that perhaps has never been seen (*).

The conscientious and enlightened minister placed at the head of the Public Works resigned his office. He was replaced by an *ad interim*, and this *ad interim* lasted... a long time. He quitted at last, and under conditions for which every body had only to congratulate himself; but at his very arrival, the inspector general of the Control Department had received the following dispatch, the epilogue of these curious incidents:

" Paris, 22nd August 1872.

I have the honour to inform you that you will have charge of the control of the railways in place of M. who himself will replace you in the direction of the control of the *Paris* to the *Méditerranée* system. This arrangement will take place from the 1st. Sept. next.

I am, etc.,

The Minister of Agriculture and Commerce, ad interim of Public Works.

Matter of course, flat refusal of the receiver.

" In your place, I should have tried to save a comrade from police prosecutions, " Such is the sole explanation (?) obtained from the *ad interim* minister who accepted the responsibility of a like measure, perhaps without rightly comprehending the seriousness of it.

It will readily be allowed that once the documents in the hands of justice, the

(*) In 1868, the government thought proper " to place at the head of the Control department engineers from the highest degres of the administrative hierarchy (a) ", and this step was applied even to the services the internal organisation of which in no way required it. It was desired to increase the authority of the Control department; in reality, the authority, the influence result less from the grade than from the character, the antecedents, and the competence of the functionary; but the intention was good.

If the grade is not a very serious element in external influence, it is evident in return, that the unjust dismissal of a head of department, is a fact the more serious, the higher his grade. It is thus that in 1872 the " Control department was elevated! "

(a) Report to the Emperor, by M. *de Forcade*, minister of Publics Works.

police prosecution was inevitable (*). In order to avert the proceedings, there was only one means: to hide from the knowledge of justice the undertaking of the 8th of January, the official letters of the 26th February and 8th June. It was necessary, having sworn to tell the truth, not to tell it! *Undertaking* or not, ministerial *decision* or not, these were official documents; it was necessary to conceal them! It was necessary to fail in the most evident, the most overwhelming of duties, it was necessary to commit really prevarication!

And again this temptation, if it had been miserably undergone and yielded to, in what would it have ended? Nothing!

How! these documents, it has been seen! they were in the hands of the whole staff of the Control Department; every one knew of them; and justice would have been ignorant of them! To believe it, very little would have to be known of what takes place after a catastrophe.

And if however it were added that the author of the preceding decision, provisionally in charge of the surveillance of railways, belonged in 1872, and had done so *for a number of years* to the *Paris-Lyons-Méditerranée* company, as a *director*, would that circumstance explain the step, or would it render it still more strange and inexplicable?

All that is deplorable.

It will be at the same time seen that silence was only broken at the last extremity. The control was silent when it was attacked on all sides, on the side where it should have found support (not for the persons but for the principles); when, in spite of the character altogether impersonal of the facts, the truth did not come precisely from where it should have been expected; when it was made to say quite the contrary to what it did say. It allowed to pass by unread a pamphlet profusely distributed, it is said, and in which, by the way, documents full of interest to the control were drawn upon, as must be admitted: so that if the publicity given to these documents constitutes an indiscretion, it is most assuredly not for the control to complain. It allowed to pass by *a fortiori*, a libel in which, it is said again, a subordinate of the company triumphed "by authority" by the rebuffs inflicted on the control (that is to say on the direction itself, seeing that they were, as has been seen in perfect agreement up to the *Champigny* catastrophe). But the day it became evident that this silence so prolonged (too far prolonged perhaps) might receive a false, although it must be admitted, a likely interpretation; that it would be inspiring doubts in the most enlightened; that it left the field clear for the most fantastical versions and twaddle; that the

(*) And the condemnation also. But for the moment, it is only a question of the sending before the court.

rectification of the incredible *error* pointed out (*) would not come; that day it was incumbent, willing or not, to quit a reserve, in which the sentiment of duty done and a legitimate contempt for little calumnies interested or complaisant, found a very peaceful refuge.

There is a word which is in every mouth: *regeneration*. In order to regenerate ourself, one must above all be possessed of principles, accept the consequences of them. A resolute survey must be made of those abuses which survive our revolutions, our disasters; which at times even seem to gain fresh vigour therein.

Some months before his death, the regretted manager of the Eastern of France lines, M. *Sauvage*, looked into the papers which have just passed under the reader's eye. " Why! it is the *Rilly* affair! " such were his first words.

And in effect, as *description*, the *Champigny* affair was the exact reproduction of the *Rilly* one. In consequence of some collisions between trains in the same direction, occurring in this long tunnel on a gradient, the Eastern of France company had informed the government that it was organising a telegraphic communication between the ends of the tunnel, which is an absolute guarantee against the simultaneous presence of two trains in the tunnel, in the same direction.

The government officially certified this declaration.

Some time after, a collision took place in that tunnel, and cost three persons their lives.

The bad state of the apparatuses, their unskilful working, the violation of their signals, would only have involved the responsibility of those engaged in working them. But the apparatuses themselves were wanting. And ascending nearer and nearer, the Court of *Reims* reached to the engineer-in-chief of the company. The administrative committee (there was no Director then, but a committee of delegated directors) not very anxious, as may be conceived, to see the responsibility continue its ascensional movement, desired that it might remain there; which, moreover, was just in itself. However, the engineer-in-chief was declared responsible for the accident, and condemned to fine and imprisonment.

So far there is the most complete analogy, almost identity between the two cases; but from that point out, what a difference!

The Eastern company does not go, contrary to all the rules of the hierarchy, carrying grievances and accusations up to the head of the State; it does not incriminate officials who have conscientiously fulfilled their duty in telling the truth

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(*) Page 846.

to justice; it does not dream of demanding overwheeningly, nor even soliciting humbly their dismissal. No one considers he has the right to demand an account from those officials of acts which arise only from the conscience, to reproach them with enlightening justice; the reports of the Control are not misrepresentations; no one sees in the conviction of the engineer-in-chief of the company, any thing else than the quite simple and necessary consequence of the principle of equality before the law; no one disavows his own acts, and the regulations, no one compromises himself in order to obtain an acquittal, which had neither to be fought, nor pursued. Every one, in a word, remains in his part, respecting that of others. A petition for pardon, accepted by the head of the State, prevents a respectable man from crossing the threshold of a prison. Principles are protected, the moral effect intact, and every one satisfied, or very nearly.

Compare, and judge... the progress.

No. **85** (page 103) *Proportions to give axles in order to avoid fractures hidden within the nave.*

With the section within the nave equal to the section of the body of the axle, the predilection of fracture for the parts near to the plane of keying is explained, as we have seen in no. 85.

The diameter must thus be increased at that dangerous part, in order that the section of greatest strain may be brought to the outside, and that the cracks, then visible, may no longer be able to escape the examiners.

For a long time, it was quite the contrary that was done. The catastrophe of June 1870 at *Newark*, on the Great Northern, was caused by the breakage of a waggon-axle (*); according to the particulars sent to me by Captain *Tyler*, then Board of Trade inspector, this axle of old make, had, where it entered into the nave, an abrupt and very considerable reduction of diameter. The fracture took place in the plane of the face of the nave itself, and an old annular fracture showed, that for a greater or less time the axle had only been resisting by a small central core.

This form has long since been condemned, but something of it still remains. If the large projection, against which it was considered advantageous for the nave to be applied, has disappeared, it too often exists in a rudimentary form, that is

(*) This accident, which cost 15 persons their lives, and injured 97 presented circumstances quite fatal. The waggon, one axle of which broke, belonged to a goods train. Some of the waggons ran off on to the other line, on which was coming up at the same moment, and before it was possible to stop it, an excursion train, which went into the waggons. The probability of such a coincidence is not quite to be overlooked on lines of great traffic. An analogous accident took place, some years since, on the Eastern of France.

to say in the shape of a small swelling out or collar with very slight projection (*Paris-Lyons-Méditerranée*, axles Pl. XII, *figs.* 58 to 65 and Pl. LXXXIX, *figs.* 19 and 20). Were it only the 25th of an inch, it is still too much; it is in no way necessary besides for keeping the distance between the wheels invariable. This collar does not exist, for example, in the axles of the carriages constructed in the *La Buire* shops (*Lyons*), for Russia. If they had the collar the carriages could only have been dispatched on trucks by the French and German lines, the gauge of which is 4 ft, 72, while the Russian lines have a 4 ft, 74 gauge.

The long turned down portions allowed the wheels to be provisionally keyed on for the dispatch at a distance back to back of wheels of 4 ft, 48; and on reaching their destination they are keyed on at their definitive distance apart of 4 ft, 74.

If the collar were necessary for waggon axles, it would of course be far more so for engines. It exists in some engines in effect, but wrongly, for it has often enough been suppressed, for example in the cranked axles represented by *fig.* 33, Pl. LXXXVII, without the exactness or the solidity of the keying on being interfered with. It is far rather in straight axles that it is of importance to do away with these collars, as it is chiefly by the cranks that cranked axles break.

The longitudinal section of the axles of the Russian waggons is not however always judicious, far from it. Those of the line from *Eletz* to *Orel* are 5 inches in the nave, and 5 ins, 08 outside. Those on the *Brest* and *Smolensk* line are equally 5 inches in the nave and 6 ins, 50 in the body, which is cylindrical. Those of the *Great Russian Society* (Pl. LXXXIX, *fig.* 18) are more satisfactory, the diameter within the nave (5 ins, 32) is not, at any rate, exceeded in other parts. It is the principle laid down by the *Vereinbarungen*, and already applied for a certain time by some *German* lines, among others, by the *Cologne* and *Minden*, and the *Saarbrücke* line : an agreement come to on the 20th of May 1869, between that company and the Eastern of France stipulated for this reciprocal condition.

A commission has been charged by the Prussian minister, with the study of a program for the construction of the carrying stock on the State railways. In its report of the 14th Nov. 1871 (*), it contented itself with fixing the principal dimensions, leaving to a special commission the task of completely determining the outline.

Load on the waggons		10 tons
Distance from centre to centre of journals		6,65 feet
Diameter	Within the nave	5,12 inches
	At the middle	4,72 »
	At the journals	3,74 »
Length of the journals		6,69 »

(*) Bericht über die Conferenz zur Berathung von Normalien für Eisenbahnwagen den Preussischen Staat's-bahnen.

The general increase of dimensions is certainly a very good step. If by so doing, breakages are avoided, no more need be said. But if it is not succeeded in avoiding breakages, they should at least be forced outside the nave. This would probably be arrived at by suppressing all enlargement and giving the keying on portion a much greater diameter. Of the ten types of axles of the *Méditerranée* rolling-stock (Pl. XII, *figs*. 58 to 65, and Pl. LXXXIX, *figs*. 19 and 20), there is not one, the outline of which is correct (*). It will doubtless be understood how necessary it is to apply, at least in the scape of a test, the above principle. We should advise also to give a slight draw, a little clearance, in the nave, in order to avoid too abrupt a change in the state of tension in the metal of the axle near the keying plane.

Nos. **164** and **165** (Pages 193 and 194).

Transport of munitions of war.

At the period of the declaration of war, in 1870, a measure which with perfect right may be termed excessive, suppressed with a stroke of the pen all the regulations respecting the transport of munitions of war of every kind. That every other consideration should give way in the case of ascertained urgency of even the most dangerous freights, was natural, but to make complete abstraction of the safety of the passengers, when no motive rendered that sacrifice necessary, was a fault.

It was dearly paid for : it caused the most terrible disaster, without doubt, of which a railway has ever been the scene : the almost total destruction of a passenger train. The remains of 63 victims were collected on the spot; several others succumbed soon after to their injuries.

This catastrophe, which took place near *Bandol* on the line from *Marseille* to *Toulon*, made but a slight noise. The country had then so many other griefs to submit to, so many wounds to heal!

What rendered it more cruel still, was that there was not the shadow of a motive for inflicting on the passengers (train 481) the risks of transport in common with dangerous materials in large mass. It was the 5th Feb. 1871, that is to say several days after the conclusion of the armistice!

Four waggons were loaded with munitions, the nature of which it has not been able to ascertain exactly. Every thing leads to the belief that the powder did not constitute the whole load. The cause of the explosion remains unknown.

(*) A part of the issue of Pl. XII contains an error, which it is requisite to correct here. The type No 4 (fig. 61) is wrongly represented as having a greater diameter at the keying on part than in the body (4,53 and 4 ins, 33); for the first figure, 4 ins, 13 must be substituted.

On the application of counterbalance weights to the driving wheels of locomotive engines; by M. NOLLAU, locomotive engineer of the Holstein railway, at *Altona*

(Translated from the *Stuttgart Eisenbahn Zeitung*, year 1848, page 323.)

" It is known that most locomotives, especially when they are hauling a small load, or when the regulator is closed during running at a high speed, convey shocks more or less jerking to their coupling with the tender. These shocks bring about the prompt destruction of the connecting link and the parts connected therewith. It is generally sought to overcome this effect by the interposition of a spring between the engine and the tender. This means ought certainly to be recommended. But if it diminishes the effects, it has no action on the cause itself. It is easy to see that the cause exists, not in the tender and the waggons, but in the engine; a little attention is sufficient to be sure that the oscillations of the latter correspond exactly to those of the piston. The shocks which are produced when the engine abruptly changes speed, for example on starting and stopping, have only a very slight relative influence. The cause of the effects I am dealing with, lies altogether in the action of the centrifugal forces, and the forces of inertia of the parts of the machinery.

" The mass of the crank and that of the portion of the connecting rods which it supports are solicited, when the driving shaft is turning rapidly, by centrifugal forces which are transmitted to the shaft and consequently to the whole engine, along a direction, which at each moment, is different. These forces are not considerable enough to produce very marked effects; but, when the piston approaches the dead point, its forces of inertia come into play. The maximum velocity of the piston is when it is at the middle of its stroke; it goes down to zero, then changes direction. The piston and its appurtenances are alternately accelerated and retarded, and the forces of inertia which correspond to this acceleration and slackening, joined with the centrifugal forces indicated, are precisely those which impart that unsteadiness in running, to the engine.

" Let us take:

" r the radius of the crank;

" q its weight, brought to the centre of the pin, including the part of the weight of the connecting rod which it supports;

" v the uniform speed along the circumference described by the centre of the crank-pin.

" The centrifugal force is

$$p=\frac{v^2}{gr}q \qquad (1)$$

"When the crank is nearly at right angles to the piston-rod, or in other terms, when the piston is at its greatest velocity, this force acts alone. To determine the force p' which produces the accelerated or retarded force of the piston, let us call l the length of the connecting rod and q' the weight of the piston and its appurtenances, including the portion of the weight of the connecting rod supported by the piston rod.

"The distance run by the piston when the crank passes from A to A' (Pl. XXIX, *fig.* 2) is

$$s = r(1-\cos\alpha) - b(1-\cos\beta)$$

"or, on account of

$$\sin\beta = \frac{r}{b}\sin\alpha, \quad \cos\beta = \frac{\sqrt{b^2 - r^2\sin^2\alpha}}{b},$$

$$s = r(1-\cos\alpha) + b - \sqrt{b^2 - r\sin^2\alpha}$$

"or as $vt = r\alpha$, t being the time, whence $\alpha = \frac{vt}{r}$,

$$s = r\left(1-\cos\frac{vt}{r}\right) + b - \sqrt{b^2 - v^2\sin^2\frac{vt}{r}};$$

"the velocity of the piston at the end of the time t, is

$$c = \frac{ds}{dt} = v\sin\frac{vt}{r}\left\{\frac{1 + r\cos\frac{vt}{r}}{\sqrt{b^2 - r^2\sin^2\frac{vt}{r}}}\right\},$$

"and because of $\quad g = \frac{q'}{p'}\cdot\frac{dc}{dt}, \quad$ whence $\quad p' = \frac{q'}{g}\cdot\frac{dc}{dt},$

$$p' = \frac{v^2q'}{g}\left\{\cos\alpha + r\,.\,\frac{b^2(\cos^2\alpha - \sin^2\alpha) + r^2\sin^4\alpha}{\sqrt{(b^2 - r^2\sin^2\alpha)^3}}\right\}.$$

"On account of the finite length b of the connecting-rod, p' is greater for the half circumference on the side of the piston than for the opposite half-circumference. Thus:

"for $\qquad \alpha = 0, \qquad p' = \frac{v^2q'}{rg}\cdot\frac{b+r}{b};$

"for $\qquad \alpha = 180^\circ, \qquad p' = -\frac{v^2q'}{rg}\cdot\frac{b-r}{b};$

"the difference is so much the greater, the less b is relatively to r. By this fact alone, long connecting rods contribute to render the running of engines steadier.

"It is only the mean value which is of consequence in practice. In order to obtain this, let us suppose the length of the rod infinite, we have then

$$p' = \frac{v^2q'}{rg}\cos\alpha.$$

" The maximum of this value, which occurs at the moment when the piston arrives at the dead point, is $p' = \frac{v^2 q'}{rg}$; that is to say an expression of the same form as that of the centrifugal force.

" We have thus:

$$p + p' = \frac{v^2}{rg}(q + q') = \frac{v^2}{rg} Q.$$

" *Thus the force which solicits the driving axle, that is to say the engine, alternately forwards and backwards, is obtained by adding to the mass of the piston and the parts which move solidly attached thereto, that of the connecting-rod, that of the crank brought to the centre of the pin, and estimating the centrifugal force of this total mass supposed concentrated in that point.*

" We have only considered one single cylinder. When the two cranks form angles of 45° with the piston-rod, the total force is

$$P = 2\left(\frac{v^2}{rg} Q \frac{1}{\sqrt{2}}\right) = \frac{v^2}{rg} Q\sqrt{2}, \tag{2}$$

" and this force soliciting the axle alternately forwards and backwards, the difference of the values of the effort of traction during one revolution reaches

$$F = 2\left(\frac{v^2}{rg} Q\sqrt{2}\right) = 2{,}828 \frac{v^2}{rg} Q. \tag{3}$$

" To eliminate then this disturbing action, there must be applied to the driving wheels, opposite the crank, masses solicited by the same centrifugal force and which, consequently, will neutralise the forces which we have been estimating.

" These deductions have been confirmed completely by the varied experiments I have made on several locomotives.

" One of the engines I tried has 15 ins cylinders and 20 inches stroke. The distance between their axles is 26 inches; the boiler is 20 feet long; the six driving wheels are 6 feet in diameter; the extreme wheels are 3 ft, 5 in diameter, having their axles at 5 ft, 5 from the driving wheels. The weight of the crank brought to the centre of the pin is 80 lbs., and the portion of the weight of the connecting rod supported thereby is 72 lbs.; we have thus $q = 150$ lbs.

" The piston with its rod, the cross head and plunger, weighs 203 lbs.; the rest of the rod 45 lbs.; so that $Q = 152 + 203 + 45 = 400$ lbs. The velocity being 6 miles an hour, or $v = 4$ ft, 3 a second:

(1) gives	$p =$ 723 lbs.
(2)	$P = 1{,}903$ »
(3)	$F = 5{,}383$ »

" In order to observe the disturbances in the movements of the engine withdrawn from all external influences, it was put in steam and suspended from the

roof of the shop by means of iron rods, taking the carrying wheels. The wheels were thus at a few inches above the rails, and not only did the suspending rods leave the system free in a horizontal direction, but also the elasticity of the wooden frame work which supported it, allowed it to take vertical movements.

" Steam being let in and the wheels run at the ordinary speed, the engine took an alternate movement backwards and forwards, concordantly with the running of the pistons, and with a total amplitude of about 4 inches. A horizontal transverse oscillation towards the smoke-box was hardly perceptible, but the vertical movements were, on the contrary, abrupt and very perceptible. This disturbance cannot be remarked under ordinary conditions, because the rails act against the motion. But it explains the fact that the tyres are ordinarily most worn in front of the crank.

" The counterbalance weights to apply for neutralising the centrifugal forces being placed at 30 inches from the axis of the axle, or at a distance of three times the radius of the crank, they should weigh :

$$\frac{1}{3} \cdot 152 \quad \text{or} \quad 51 \text{ lbs.}$$

" As soon as they were put in place, all tendency to vertical movements disappeared completely, even when the wheels made 250 revolutions a minute ; but the horizontal backwards and forwards movement was still marked. It disappeared in its turn, when the counterbalance weight was increased to $\frac{1}{3} \times 400 = 133$ lbs. But then the vertical movement returned, and accompanied by a horizontal and transversal oscillation of the front of the engine. In effect, on the one part, the counterbalance weights were naturally too much for the vertical disturbance ; on the other, they were moving in vertical planes twice as far away from the diametrical plane of the engine than the masses of the pistons to neutralise.

" I adopted for this engine the mean, or 92 lbs. This application dates back now about a year (1847) ; the parts of the coupling have not ndergone the least change, while before the application of the counterbalance weights and in spite of the introduction of a buffing and drawing spring, the bolts were always sheared, and the plates of the coupling torn. Besides, the running of the engine has surprisingly gained in regularity.

" I proceeded in the following manner to observe the backwards and forwards horizontal movement :

" 1st. The engine being placed on a very horizontal piece of road, the rails were removed from under the driving wheels, and the steam was put on without the carrying wheels being fixed.

" 2nd. The engine was started at the ordinary velocity drawing only its tender, and the coupling bolt having 2 inches play.

" It was ascertained in these two experiments that with a counterbalance weight

of 133 lbs there was not the slightest shock, while as soon as it was reduced or increased by only a score of pounds, the irregular movements became very sensible.

" Engines with coupled wheels and inside cylinders can generally do without counterbalance weights; the outside cranks, keyed on at 180° with the driving cranks, and the coupling rods already fulfil, in effect, the functions of counterbalancing. Such is the reason of the stability possessed by these engines, which diminishes if the coupling rods are taken off.

" Locomotives with outside cylinders present the well known disadvantage, that at each stroke of the piston the front of the engine is thrown with more or less force from left to right and from right to left. The greatest possible trouble has been taken to discover the cause of this tendence, of which divers explanations have been given; it has been particularly attributed to the variations to which the pressure on the front springs is subjected by reason of the obliquity of the connecting-rods; to which may be objected that in engines with horizontal inside cylinders a regular oscillation of the spring scan scarcely be noticed. Besides, were it more marked, it could not impart to the engine, the transverse movements observed. But of all the objections, the most decisive is, that the disturbance in question persists even when the regulator is closed.

" When the cylinders are inside, and consequently little distant from the mean plane of the engine, the disturbing actions of the two pistons are reduced nearly to one force situated in that plane. With outside cylinders, on the contrary, the engine is solicited to oscillate round an imaginary vertical axis; but the instability of these engines may be all the better remedied by the application of suitable counterbalance weights : these weights and the pistons being nearly at the same distance from the axis of the engine.

" The engines which present the most unfavourable conditions are those which have at the same time outside cylinders and coupled wheels, because the coupling parts are then themselves elements of disturbance, instead of being, as in the case of inside cylinders, elements of neutralisation. Very heavy counterbalance weights thus become necessary; they can however be conveniently distributed over the coupled wheels.

" Let us take for example, for an engine with four wheels coupled, with 24 inch stroke and 5 feet driving wheels :

Weight of piston with its appurtenances	190 lbs
Connecting rod	106 »
Coupling rod	104 »
Portions out of centre of the two cranks (driving and coupling) referred to the centre of the pin	50 »
	450 »

" The counterbalance weight having its centre of gravity at 25 inches from

the centre of the axle, it would have to be brought, so as entirely to destroy the zigzag movement, to $\frac{17}{25} 440 = 216$, or 108 lbs. on each of the driving wheels; but in order not to overpass too far vertical equilibrium, it is expedient to stop a 80 lbs.

"In three cylinder engines the forces of inertia act on each side, with equal intensities, and in the same direction at each moment. There is thus no tendence to the zigzag movement; but the longitudinal backwards and forwards movement exists, and the counterbalance weights are on that account as necessary in these engines as in the others."

No **301** (page 393).

M. Schivre's cranked axles.

Some of these axles have run considerable distances.

The 23rd of May 1863, the cranked axle of engine 284 broke near *Ilfurth*.

It was one of the gudgeons which broke, a little within the dowel in the arm of the crank, and quite close to the shoulder forged of the gudgeon. A circular zone 0,12 of an inch wide indicated an old fracture.

The circumstances were, in a word, very analogous to those presented by the breakage of waggon axles in the nave.

The axle of this engine No. 284 had run 357.572 miles, a very high figure for a cranked axle (305, 2) and which would tend to warrant the method of construction adopted by M. *Schivre*. But that is in question of the little old engines of the Alsace line; and we know that, all things besides equal, the distance run by cranked axles decreases as the power of the engines increases, in spite of the increase of the dimensions.

No **411** (page 696).

Ventilation of the Edge Hill tunnel, at Liverpool.

It was only in 1870 that the locomotive took the place, in this tunnel, of the cable. But the activity of the traffic, concentrated on this point, on account of the position of the tunnel between two neighbouring stations, most urgently required a very energetic mechanical ventilation. This is done by a sucking fan of sheet iron, installed in a brick chamber surmounted by a chimney of very large section rising 200 feet above the rails. Its axle is driven directly by the connecting rods of two conjugate engines running at 45 revolutions. For such slow rotatory speed, the diameter of the fan is required to be nearly 30 feet.

The apparatus does not work continuously. The driver starts it on a signal, and continues working it until a fresh signal from outside warns him that the air is coming out of the well without being accompanied by smoke or steam.

No. **163** and following.

Experimenting with the Agudio system on Mount Cenis.

Length of the inclined plane..	7.546 feet.
Maximum gradient. . . . . one in	2,62 "
Height got over.	1.763 "
Gauge of the line from centre to centre of rails	4,92 "
Radius of curves	492 "

Hydraulic motor and transmissions to the fixed motor pulleys.

Force on the horizontal shaft of each of the two turbines (*Girard's* system), in horse-power.	500 horse-power.
Height of the fall.	459 feet.
Internal diameter of the wrought iron conduit.	216 "
Length do. do.	1.400 "
Diameter of the turbines	590 "
do. grooves in the motor pulleys.	13,12 "
Number of turns per minute of the turbines.	300
do. do. motor pulleys	60 "
Ratio of the gearwork	1:5
Tangential velocity of the turbine	92,74 feet.
do. effort of do.	1,326 tons.
do. velocity of motor pulley $\frac{1}{5} \times \frac{13,12}{5,90} \times 92,74 = 0,479 \times 92,75 =$	41,26 feet.
Tangential effort on the motor pulleys due to the work of one turbine $= \frac{1,326}{0,444} =$	2,987 tons.
Available effort on each of the two ropes, reckoning the losses due to the transmission and the stiffness of the rope at $\frac{1}{10}$th, the rope taking two half turns round the motor pulleys $2.987 \times (1 - 0.10) =$	2,689 tons.

Teledynamic transmission by the descending lines of the ropes outside the line.

Rectilinear run of the lines of rope inclined $\frac{1}{3}$ rd.	41,3	feet.
Distance between the supporting pulleys.	262,5	"
Diameter of do.	3,28	"
do. mean of the axles of the pulleys = ...	1,38	inches.
Weight of a pulley	88	lbs.
Weight of the rope per lineal yard.	3,0	"
Load on the axle of the pulley $\frac{2}{3} \times 3{,}0 \times \frac{262{,}5}{3} + 88 =$	263	"
Total of the resistances of teledynamic transmission referred to the circumference of the pulleys, the bearings of which are in constant lubrication $0{,}06 \times \frac{0{,}1148}{3{,}28} \times 263 \times \frac{5413}{262{,}5} =$	9,76	"

Guiding pulleys at the summit of the inclined plane.

Horizontal traction exerted on the axes of the guiding pulley taking into account the component of the gravity of the rope: $2{,}689 - 0{,}00443 + \frac{1763 \times 1.0}{2240} =$	3,490	tons.
Weight of the pulley	1,250	"
Resulting pressure on the axles $R = \sqrt{(2 \times 3{,}490)^2 + \overline{1{,}250}^2} =$	7,009	"
Resistance referred to the circumference $0{,}06 \times \frac{0{,}426}{13{,}12} \times 7{,}009 =$	30.14	lbs.

0 426 foot being the diameter of the steel axles and 13,12 feet the diameter of the semi-pulley.

The resistance due to the stiffness of the cable on the groove in circumference is expressed approximately by $\frac{d}{D} \times \frac{Q}{2}$ (*);

(*) The simple proportionality of the stiffness to the diameter of the rope was verified experimentally at *Dusino*, but it applies only to the mode of construction characterising it, and which gives for an equal diameter, great relative flexibility. This law could not then, be extended to ropes entirely of metal. Besides the experiment was only made on diameters, comprised betwen 0,50 and 1,0 inch.

d being the diameter of the rope $= 0$ in, 90, D that of the pulley $=$ 13 ft, 12, Q the tangential effort, which gives, $\frac{0{,}075}{13{,}12} \times \frac{3{,}490}{2} =$ . . . . 229,46 lbs.

Ascending lines of the rope, along the line.

The guiding rollers of the rope on the curves of the line, the radius of which is 492 feet, being 11 ft, 8 apart will support a lateral pressure which will go on increasing from the bottom to the top of the plane. Only taking into account the resistances proper of the rollers, the mean tension T of the ascending line of the rope will be equal to the effort available on the circumferences of the motor pullies, diminished by the resistances which the rope encounters by the teledynamic transmission, and augmented by the half of the vertical component of the total weight of the cable, namely:

$$T = 2.689 - \frac{(9{,}76 + 30{,}14 + 229{,}46)}{2{,}240} + \frac{1790{,}7}{2+2{,}240} = \quad 2{,}97 \text{ tons.}$$

The mean pressure on the axles of the rollers due to this tension is $P = 2 \sin \frac{1}{2} \alpha \times T$, and α being $= 1^\circ\ 27'$,

$P = 2 \times 0{,}011926 \times 2{,}970 =$ . . . . 156,22 lbs.

Neglecting the action of the vertical component of the weight of the rope on each roller, which is insignificant compared to P, the mean resistance on the guiding rollers, in constant lubrication, referred to their circumference, is

$0{,}06 \times \frac{0{,}082}{1{,}05} \times 156{,}22 =$ . . . . 0,731 lbs.

The weight of the roller being 55 lbs. the resistance to rotation of the vertical axle of the roller is

$\frac{1}{2} \times 0{,}06 \times \frac{0{,}082}{1{,}05} \times 55 =$ . . . . 0,171 "

Mean resistance on the guiding rollers,

$0{,}731 + 0{,}171 =$ . . . . 0,902 lbs.

And on the 236 rollers for one rope there will be

$0{,}902 \times 236$ . . . . 212,87 lbs.

On the straight parts, the rollers being 4,59 feet apart and their weight being 33 lbs., the sum of the resistances on the 192 corresponding rollers is

$0{,}06 \times \frac{0{,}066}{0{,}082} \times (33 + 30{,}89) \times 192 =$ . . . . 58,95 lbs.

Taking into account the vertical component of the weight of the rope, which is $\frac{2}{3} \times 1{,}0$ lbs $\times 45{,}9$ feet $=$ . . . . 30,6 lbs

Transmission of the work to the locomotors.

In order to utilise the one thousand horse-power of the two turbines, use is made of two locomotors coupled together, and having to push the train up the incline. Each of the two ropes passes from one locomotor to the other, taking a turn round the one of the two couples of pulleys 8,2 feet in diameter, of each apparatus. The tangential effort θ, transmitted by one of the ropes to the two couples, is equal to the effort of the fixed motor pulleys, diminished by the sum of all the passive resistances which the rope has encountered on its run from the motor to the locomotors. There is thus :

$$\theta = 2{,}689 - \frac{(9{,}76 + 30{,}14 + 229{,}46 + 212{,}87 + 58{,}95)}{2.240}$$

$= 2{,}689 - 0{,}245 =$ . . . . 2,443 tons.

It may be admitted that the transmission of this effort to the horizontal pinions acting on one of the sides of the rack will absorb 10 per cent, namely:

$\frac{1}{10} \times 2{,}443 =$ . . . . 0,244 "

The real effort transmitted to the circumferences of the pinions the speed of which is four times less, is:

$4 \times (2{,}443 - 0{,}244) = 4 \times 2{,}199 =$ . . . . 8,796 tons.

The effort on the tooth of the double rack, on which four pinions act on each side, is then,

$\frac{1}{4} \times 8{,}796 =$ . . . . 2,199 tons.

The total effort of traction of the two locomotors is thus:

1. Direct traction of the two cables $2 \times 2{,}443 =$	4,887 "
2. Traction by the intermedium of pinions $8 \times 2{,}199 =$	17,593 "
Total.	22,480 tons.

Weight of the train drawn up the one in 2,62.

The effort necessary to draw one ton up the maximum gradient of 38 per cent, is 837,76 lbs + 8,82 lbs. . . .	846.58 lbs.
The number of tons, including the weight of the two locomotors of 11 tons each, will be	
$\frac{22.480}{0.384} =$	58,6 tons.
and the number of tons of the train will be $58{,}6 - 22 =$	36,6 "
The useful work	
$36{,}6 \times 0{,}384 \times \frac{41{,}26}{5} = 14{,}05 \times 8{,}25 =$	115,91 foot tons.

and the return $\frac{115{,}91}{250} = 47$ per cent.

This result has its importance, on account of the excessive inclination of the plane. For gradients of from 18 to 20 per cent, to which the system is particularly applicable, the load of the trains drawn would amount to 100 tons, and the return to 60 per cent.

Resistance of the rope.

The point when the cable is the most strained corresponds to its unrolling out of the groove of the summit guiding-pulley. At this point the tension is:

$$2{,}689 + \frac{1790{,}7 + 9{,}76}{2240} = 3{,}491 \text{ tons.}$$

The metallic section of the cable, formed of six strands of eight steel wires of 0,10 inch in diameter with seven cores in tarred hemp, being 0,279 square inches, the tension on the square inch is:

$$\frac{3{,}491}{0{,}279} = 12{,}50 \text{ tons,}$$

which is about the fifth part of the breaking weight. These are the conditions under which the *Liége* inclined-plane cables work, but with the difference that

in this case the rope, independent of any fixed point, is acted on by a strain always limited by the adhesion.

Action of the strainers at the foot of the inclined plane.

The grooves of the locomotor-pulleys are fitted with rope aloe fibre of which greatly increases the hold of the rope on the pulley. The draw of the strainers is regulated by a dynamometrical apparatus, which allows its amount to be observed. Each couple of pulleys having to transmit an effort:

$$Q = \frac{2{,}443}{2} = 1{,}222,$$

the value of the tension will be

$$t = \frac{1{,}222}{\frac{fs}{e^r} - 1} = \frac{1{,}222}{4{,}806} = 0{,}255 \times 2{,}240 = 562 \text{ lbs},$$

taking $f = 0{,}56$, value given by experiment.

Locomotor brakes.

The four blocks acting on the friction circles f, f of the shafts of the horizontal pinions produce a resistance to the motion of:	
$0{,}20 \times 4 \times 18{,}00 =$	14,40 tons.
The two jaws grip the central longitudinal with a pressure of 16,00 tons, produce $0{,}32 \times 16{,}00$	5,12 "
The four clutches allow the adhesion of the two ropes on the pulleys to be utilised as means of resistance to the motion of the train down the incline. This adhesion is.	5,0 "
The total power of the brakes is	24,52 tons.
and for the two locomotors $2 \times 24{,}52 =$	49,04 "

Whence it results they will never have to work beyond the one quarter of their power, and that strictly speaking the down train can be kept in check, by means of one only of the three brakes, acting on the rack and on the central longitudinal, without needing any brake on the waggons.

Number of tons that the apparatus can take in a day's work of sixteen hours.

The vertical velocity of the train being $0.381 \times 8.24 =$ . .	3,14 feet.
The time necessary to mount the 1.763 feet between the two extreme stations will be	
$\frac{1763}{3{,}14} = 551'' =$	9′ 25″
or 10 minutes.	
Admitting that the descent of the train is done at the same rate, and that the station operations take up the same amount of time, in each half-hour a train of 36 tons will be hauled up, which will give for the day's work of 16 hours, and in both directions a total of:	
$2 \times 32 \times 36 =$	2.304 tons.
a very considerable figure for a single line.	

Cost of construction.

Formation level.	£ 6.400
Permanent way and rack.	4.200
Covering over the line (with the old galleries of the *Fell* line).	3.480
Hydraulic establishment.	3.400
Rope transmission and locomotors.	5.600
Sundries.	920
Total.	£ 24.000

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— 139. Line 13, *for :* Lloyd Hoster, *read :* Lloyd Foster.

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— 176. Line 14 from below, *for :* same, *read :* sum.

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— 231. Line 2 from below, *for :* $\overline{<}$ *read :* $\overline{\overline{>}}$

— 233. Line 5, *for :* T^{bp}, *read :* I^{fp} ; *and for* $V^{b''}$, *read* $V^{f''}$.

— 256. Last line, *for :* tus thhe, *read :* thus the.

— 257. Line 15, *for :* of 1 in, 37 where, *read :* of one in 37, where.

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— 271. Line 14 from below, *for :* *Trewithick*, *read :* *Srewithick*.

— 272. Line 20, *for :* coontor, *read :* couter.

— 277. Line 1, *for :* rect, *read :* direct.

— 288. Line 6 from below, *for :* it run, *read :* it ran.

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— 342. Line 6 from below, *for :* thus to point, *read :* thus, by the point.

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— 401. Line 6 from below, *for :* sooner, *read :* sooner than.

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— 440. Line 6, *for :* by making with, *read :* by means of.

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— 457. Line 1, *for :* Mr. *Adam*, *read :* Mr. *Adams*.
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— 640. Line last, *for :* is the true, *read :* It is the true.
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— 757. Line 19, *for :* cinq, *read :* five.
— 760. Line 1, *for :* tallen, *read :* given.
— 770. Line 11, *for :* the Court of Paris law, *read :* justice.
— 771. Line 10, *for : behind*, *read :* behind time.
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